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16. ABSTRACT

This report provides cost-effectiveness data for methods of controlling hydrocarbon emissions from industrial sources in the five-county Nashville metropolitan area. A baseline inventory of hydrocarbon emissions from the graphic arts, gasoline marketing, gasoline bulk storage, surface coating, organic chemical production, rubber processing, dry cleaning, and degreasing industries is presented. Control methods are defined which could reduce hydrocarbon emissions in the study area by 60 to 80 percent. Capital costs and net annualized costs for the control methods at model plants are given. Net annualized costs ($/yr) and estimates of the quantity of hydrocarbons controlled (tons/yr) for model plants are used to calculate the cost effectiveness of the hydrocarbon control methods. There are wide variations in the cost effectiveness of the control methods depending on the application. This variation in cost effectiveness will be useful in developing a hydrocarbon control strategy, because it shows how to achieve the largest reduction in hydrocarbon emissions at the smallest cost.

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Prepared for

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1.0 INTRODUCTION AND SUMMARY

This report describes the results of a program to provide cost-effectiveness data for methods of controlling hydrocarbon emissions from stationary sources in the five-county Nashville metropolitan area. The work was conducted for the Environmental Protection Agency, Air Engineering Branch, Region IV, under Radian Contract 68-02-2608, Task 5.

1.1 Background and Approach

This study was done to assist Tennessee state and local agencies in revising the state implementation plan. The purpose was to provide a basis for evaluating the economic impact of hydrocarbon control strategies. There were four steps involved in determining the cost effectiveness of hydrocarbon control methods.

First, a baseline hydrocarbon emission inventory was compiled for the five-county study area using inventory data from state and municipal agency files. The sources and quantities of emissions were defined. Then, methods for controlling the hydrocarbon emissions at typical model facilities were identified and hypothetical reductions in hydrocarbon emissions were estimated. Next, capital costs and net annualized costs for the control methods were derived from published cost information for model plants. Finally, the cost effectiveness in dollars per ton of hydrocarbon controlled was determined. Published information on the economic impacts of control methods for some of the industries was also reported.

1.2 Summary of Results

1.2.1 Emission Inventory

Baseline hydrocarbon emissions in the study area in 1975 were about 17,700 tons/year.* About 55 percent of the emissions were produced in Davidson County, 29 percent in Sumner County, 9 percent in Rutherford County, 4 percent in Willimason County and 3 percent in Wilson County. Some increases in current (1977) emissions have been noted; an incomplete estimate of 1977 emissions is about 21,000 tons/year.

Eighty percent of the hydrocarbon emissions in the study area are produced by six industrial operations; graphic arts (printing), gasoline marketing, gasoline bulk storage, surface coating, and organic chemical processing. The majority of emissions from printing and organic chemical manufacture are produced by single large emission sources (over 1,000 tons/year). Emissions from gasoline marketing are produced by hundreds of small sources (less than 10 tons/year). The majority of emissions from gasoline storage and surface coating are produced by sources with emissions from 10 to 200 tons/year. Less significant sources of emissions in the study area include rubber processing, dry cleaning, and degreasing.

1.2.2 Control Methods and Potential Reduction in Hydrocarbon Emissions

Table 1-1 shows how hydrocarbon emissions from each of the eight industrial emission sources might be reduced using various selected control methods. The sources of emissions in

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*Hydrocarbon emissions are reported in short tons/year. Conversion factors for metric units are given in the Appendix.

TABLE 1-1. METHODS OF CONTROLLING HYDROCARBON EMISSIONS FROM INDUSTRIAL SOURCES IN THE NASHVILLE AREA

Emission Source	Hydrocarbon Emissions (tons/yr)	Control Method	Control Efficiency (%)	Emissions After Controls (tons/year)	Percent Reduction In Emissions
Graphic Arts[a]					
Gravure Printing	3,886	Carbon adsorption	90	390	
Web Offset and Letterpress	52	Catalytic incineration UV curing ink	85 100	0-8	
Flexography	60	Incineration	85	9	
Controlled and Other Sources	517	None specified	—	517	
	4,415			915-923	80
Gasoline Marketing[b]					
Storage Tank Filling	1,670	Stage I controls: submerged fill + vapor balance recovery	95	1964 (Stage I alone)	45
Vehicle Refueling	1,880	Stage II controls:			
	3,550	vapor balance vacuum assist	85 90	272-306 (Stage I + Stage II)	92
Bulk Gasoline Terminals[c]					
Tank Truck Loading	2,840	Submerged fill	58	1,190	58
		Submerged fill plus vapor recovery by straight refrigeration	87	155	95
Surface Coating[d]		Add-On Devices:			
Spray Booth Emissions	731	Carbon adsorption	85	110	
Drying Oven Emissions	145	Incineration	90	15	
Other Emissions	924	None specified	—	924	
	1,800			1,049	42
		Process Change, Coating Substitutions:			
Wood Coating	291	Water-borne coatings	75	73	
Metal Coating	820	Electrostatic spraying, powder coatings	99	8	
Plastic Coating	299	Low solvent, high solids coatings	50	150	
Other Emissions	390	None specified	—	390	
	1,800			621	65

TABLE 1-1 (Continued)

Emission Source	Hydrocarbon Emissions (tons/yr)	Control Method	Control Efficiency (%)	Emissions After Controls (tons/year)	Percent Reduction In Emissions
Organic Chemical Production[e]					
Terephthalic Acid Absorber Off-Gas	2,870	Incineration	90	287	
DMT Storage and Sludge Bottom Tank Vents	33	Fuel oil scrubber	90	3	
Product and Methanol Storage Tanks	90	Water scrubber	90	9	
Gluing Process Labels	5	Process change	100	0	
Other Emissions	402	None specified	--	402	
	3,400			701	80
Rubber Tire Manufacture[f]					
Dipping Bead, Cord, and Belt	66	Carbon adsorption	90	7	
Green Tire Spray	417	Substitute water-based release agent	100	0	
Tread Cementing	182	Collection system plus carbon adsorption	85	27	
Other Emissions	83	None specified	--	83	
	750			117	84
Dry Cleaning[g]					
Petroleum Solvents	460	Improved housekeeping and operating practices	17-25	500	33
Synthetic Solvents	188				
	648	Improved practices and carbon adsorption	67-79	159	75
Degreasing[h]					
Open Top Vapor Degreasing	100	Improved housekeeping and operating practices	30	200	30
Conveyorized Degreasing	190				
	290	Improved practices and carbon adsorption	50	100	65

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[a] See Table 4-6.

[b] See Table 5-3.

[c] See Section 6.0.

[d] See Table 7-14.

[e] See Table 8-2.

[f] See Table 9-13.

[g] See Table 10-8.

[h] See Section 11.3.

each industry are defined and control methods and efficiencies are identified for each source of emissions. Control methods were generally identified based on guidelines published by EPA, but in some cases the control methods were specified by industry representatives for the specific plant in the study area. More than one control method is available for some of the emission sources, but for others a single control method has the best applicability. Table 1-1 also shows the estimated rate of hydrocarbon emissions after implementation of the control methods.

Table 1-2 summarizes the information on potential reduction in hydrocarbon emissions from Table 1-1. It shows that industrial hydrocarbon emissions in the study area theoretically could be reduced from baseline emissions of about 17,700 tons/year to about 3,100 - 6,600 tons/year using the control methods identified in Table 1-1. The selected control methods could provide a 62 to 83 percent reduction in baseline emissions.

1.2.3 Control Costs and Cost Effectiveness

Information on capital investments and net annualized costs for the control methods was taken primarily from EPA guidelines for model plants. An attempt was made to indicate how well the model plants represented the actual plants in the study area. But for some industries there was very limited information about the capacity and operating conditions of plants in the study area. In such cases, cost data were provided for large and small plants typical of the industry in general and for a range of operating conditions if possible. Information on cost of control methods for two industries was supplied by the operating companies.

TABLE 1-2. SUMMARY OF POTENTIAL REDUCTIONS IN HYDROCARBON EMISSIONS FROM EIGHT INDUSTRIAL SOURCES IN THE NASHVILLE AREA

Industry	Hydrocarbon Emissions (tons/yr)	Emissions After Controls (tons/yr)			Percent Reduction
Graphic Arts	4,415	923	-	915	80
Gasoline Marketing	3,550	1,964 (Stage I)	-	306 (Stage I & Stage II)	45 - 92
Tank Truck Loading at Bulk Gasoline Terminals	2,840	1,190 (Submerged Fill)	-	155 (Submerged Fill + Vapor Recovery By Refrigeration)	58 - 95
Surface Coating	1,800	1,049 (Carbon Adsorption + Incineration)	-	621 (Process Change)	42 - 65
Organic Chemical Production	3,400		701		80
Rubber Tire Manufacture	750		117		84
Dry Cleaning	648	500 (Improved Housekeeping and Operating Practices)	-	159 (Improved Housekeeping + Carbon Adsorption)	33 - 75
Degreasing	290	200 (Improved Housekeeping and Operating Practices)	-	100 (Improvide Housekeeping + Carbon Adsorption)	30 - 65
TOTAL	17,693	6,644	-	3,074	62 - 83

The capital costs reflect the cost of designing, purchasing, and installing the control device. These estimates include the cost of both major and auxiliary equipment, removal of any existing equipment, site preparation, equipment installation, and design engineering. The estimates do not include costs for lost production during equipment installation or start-up.

The net annual cost (or credit) is composed of direct operating costs, capital charges, and solvent or gasoline recovery credit (where applicable). The direct operating costs include operating labor, maintenance, utilities, and supplemental fuel. Capital charges include depreciation and interest costs at 10 percent and a depreciable equipment life of 15 years and an additional charge of 4 percent of total capital for administrative overhead, property taxes, and insurance. Published cost data were converted to first quarter 1977 dollars using plant and equipment cost indexes (Chemical Engineering, July 4, 1977).

Cost data were not available for some of the control methods. While costs were generally available for add-on control devices such as incinerators or carbon-bed adsorbers, costs for process change and improvements in housekeeping and operating practices are not well defined. In some cases both capital and annual costs for improved operating and housekeeping practices are negligible, and a net savings in annualized costs is provided due to credit for recovered hydrocarbons. Costs for process change are hard to estimate because it is difficult to define what portion of the development costs will be borne by the supplier and what portion will be borne by the user.

Net annualized costs ($/year) and estimates of the volume of hydrocarbons controlled (tons/year) for model plants were used to calculate the cost effectiveness of hydrocarbon control methods. Table 1-3 summarizes the results. In general, the cost effectiveness data are given for control methods implemented at model plants, but for organic chemical production and tire manufacturing the cost effectiveness was estimated by the operating companies. The cost effectiveness of the control methods shown in Table 1-3 varies from a cost of $4,800/ton controlled to a credit of $530/ton controlled. The hydrocarbon emissions in the study area to which the control methods can be applied are also indicated in the table. These data can be used in developing control strategies because they indicate the most effective way of spending control dollars. The most effective control strategy would involve controlling the highest volume of hydrocarbon emissions with the most cost-effective control methods (the methods with lowest cost per ton controlled).

1.3 Report Organization

Section 2.0 presents the conclusions from this study. The emission inventory is described in Section 3.0. Sections 4.0 through 11.0 describe eight industrial sources of hydrocarbon emissions in the study area. The source categories include graphic arts (Section 4.0), gasoline marketing (Section 5.0), tank truck loading at gasoline bulk terminals (Section 6.0), surface coating (Section 7.0), organic chemical processing (Section 8.0), rubber processing (tire manufacture) (Section 9.0), dry cleaning (Section 10.0), and degreasing (Section 11.0). Details are given in each section on how emissions are produced in the operations, the facilities that produce the emissions and their emission rates, control methods, potential reductions in emissions, cost of controls, cost effectiveness, and economic impact. Appendix A contains conversion factors for metric units.

TABLE 1-3. SUMMARY OF COST EFFECTIVENESS DATA FOR HYDROCARBON CONTROL METHODS

Industry and Emission Source	Control Method	Model Plant Cost Effectiveness ($1,000/Ton Controlled)	Study Area Emissions Treated (tons/yr)	Reference
Graphic Arts				
Rotogravure Printing	Carbon adsorption	(0.1)	3,886	Table 4-8
Web Offset Lithography	Catalytic incineration	1.8	52	Table 4-10
Gasoline Marketing				
Storage Tank Filling	Stage I controls: Submerged fill and vapor recovery	(0.02)	1,670	Table 5-4
Tank Filling and Vehicle Refueling	1. Stage I controls plus balance system	0.81	3,550	Table 5-4
	2. Stage I controls plus vacuum assist	2.32	3,550	Table 5-4
Gasoline Bulk Terminals				
Tank Truck Loading	1. Submerged fill	(0.11)	2,840	Table 6-3
	2. Submerged fill plus refrigeration	0.8 - 0.1[a]	2,840	Table 6-3
Surface Coating				
Drying Oven Exhaust	Incineration with primary heat recovery	4.8 - 0.07[b] 3.3 - 0.03[b]	145	Table 7-16
Organic Chemical Production				
Absorber off gas	Incineration	0.67[c]	2,870	Section 8.2
DMT Storage	Fuel oil scrubber		33	
Product and Methanol Storage	Water Scrubber		90	
Gluing Labels	Process Change		5	
Rubber Tire Manufacture				
Dipping	Carbon adsorption	0.16 - (0.02)[d]	66	Table 9-12
Cementing	Carbon adsorption	0.08 - (0.02)[d,e]	182	Table 9-12
Green Tire Spraying	Substitute waterborne release agents	0.7[c]	417	Table 9-12
Dry Cleaning				
Petroleum Solvent	Improved housekeeping plus carbon adsorption	0.03 - 0.67[f]	460	Table 10-8
Perchloroethylene Solvent	Improved housekeeping plus carbon adsorption	(0.37)[g] (0.16) (0.53)	188	Table 10-8
Degreasing				
Open Top Vapor Degreaser	Improved housekeeping plus carbon adsorption	0.22	100	Table 11-5
Conveyorized Degreaser	Improved housekeeping plus carbon adsorption	(0.11) - 0.26[h]	190	Table 11-5

[a] 0.8 for model small plant, 0.1 for model large plant.

[b] Range of values due to variations in hydrocarbon concentration in oven exhaust. 3.3-0.03 for large plant, 4.8-0.07 for small plant.

[c] Cost effectiveness for actual plant rather than model plant based on estimate provided by plant representative.

[d] Lower value for case with no credit for recovered solvent, higher value for case with solvent credited at market value.

[e] Industry estimate 0.2.

[f] 0.03 for industrial plant. 0.67 for commercial plant.

[g] (0.37) for industrial facility. (0.16) for commercial facility. (0.53) for coin-operated facility.

[h] (0.11) - monorail
0.26 - crossrod

2.0 CONCLUSIONS

A significant (60-80 percent) reduction in industrial hydrocarbon emissions in the Nashville area could be provided in theory by application of the control methods identified in this study. There are wide variations in the cost effectiveness of the control methods depending on the specific application. Some provide an annual credit, while others cost thousands of dollars for each ton of hydrocarbons controlled. This variation in cost effectiveness will be useful in developing a control strategy because it shows how to achieve the largest reduction in hydrocarbon emissions at the smallest cost.

These conclusions are based largely on estimated emission rates and control efficiencies. Control methods were specified using general guidelines for model facilities published by EPA. Cost effectiveness data were calculated on the basis of controls applied at model plants which may not be entirely representative of actual facilities in the study area. The resources available for this generalized study did not permit detailed characterization of actual industrial operations in the study area. As a result, no judgements can be made about the applicability of control methods or the accuracy of cost estimates for specific facilities in the study area.

3.0 HYDROCARBON EMISSION INVENTORY

A 1975 baseline inventory of the stationary sources of hydrocarbon emissions was established for Nashville and the surrounding area. The study area for this emissions inventory includes the Tennessee counties of Davidson, Rutherford, Sumner, Williamson, and Wilson.

3.1 Inventory Basis

Hydrocarbon emission rates are given in short tons (2000 lb) per year for each county in the study area. The emissions are further categorized according to the type of operation (source category) that produces them. Examples of the twelve types of operation (source categories) which produce hydrocarbon emissions in the study area are degreasing, gasoline marketing, and dry cleaning.

Emissions in each source category arise from major and minor point sources and area sources. A major point source has been defined in this inventory as a stationary source emitting in excess of 25 tons per year of hydrocarbons. A minor point source is a stationary source emitting less than 25 tons per year of hydrocarbons. Area sources include minor sources which are not individually identified. The area source emission values are based on the estimated throughput of an emission-generating substance and the appropriate emission factor for that substance.

Even though the inventory represents emissions for 1975, it incorporates some unadjusted 1974 and 1976 data. It was assumed that differences in annual emission rates during these three years were small.

3.2 Information Sources

The information used for this inventory was supplied by state and local agencies and supported with information from several of the emitting firms. The data for point sources in Davidson County were provided by the Metropolitan Health Department in Nashville. These figures were compared with current data by reviewing local permit files. The area source emission data for Davidson County were provided by this review. For the four surrounding counties, the information had been previously gathered and tabulated in the "HC Report."[1] This report, supplied by the Tennessee Health Department, was the source of most of the data for the four counties. Emission data for dry cleaning, gasoline stations, and fuel and refuse burning were not included in information from local files. Information for these three source categories was available from an EPA-funded study of hydrocarbon emissions in the study area.[2]

Other sources of information were provided by the Tennessee Health Department and were cross-checked with the previously mentioned sources of data. An Emission Inventory Subsystem (EIS)[3] printout for the four counties supported the inventory figures. A "No-Source" list from local files was also checked against the "HC Report," showing a few minor discrepancies. Some "no-source" firms were listed in the "HC Report," but they had negligible emissions so no alterations were made to the inventory.

A National Business List (NBL) of firms that are potential hydrocarbon emitters in the five counties was reviewed.[4] Using the criteria of financial strength and/or employment level, possibly significant hydrocarbon emitters were identified. The names of these firms were sent to the local agencies for review.

It was determined that one of the firms was a significant emitter, company DG-2 in Rutherford County. Thus, the baseline inventory was changed to include emissions from the degreasing operations at DG-2's plant.

3.3 Results

The 1975 baseline emissions inventory is presented in Table 3-1. The inventory gives the hydrocarbon emission rate for each source category in the five counties and emission totals for each category and each county. A breakdown of the emission totals by percent is also presented for each county. Table 3-1 shows that over half of the hydrocarbon emissions in the study area occur in Davidson County.

Table 3-2 lists the significant source categories and the percent of total hydrocarbon emissions from each in 1975. Some current (1977) data are also included. The table shows that the majority of 1975 emissions occurred from printing (graphic arts), gasoline marketing, gasoline bulk storage and surface coating operations. Based on more current (1977) estimates for some of the categories, the significant contributors are printing, gasoline marketing, gasoline storage and chemical processing.

Table 3-2 also gives information about the number of large (major point) sources that emit hydrocarbons in each category. A significant percentage of the emissions in most categories are contributed by major point sources (those with emissions greater than 25 tons/year). Gasoline marketing and dry cleaning are exceptions. Hydrocarbons from these operations are emitted from numerous small sources rather than a few major sources.

Sections 4 through 11 discuss hydrocarbon emissions from eight of the twelve source categories. Emission rates and

TABLE 3-1. BASELINE INVENTORY OF 1975 HYDROCARBON EMISSIONS FROM STATIONARY SOURCES IN THE FIVE-COUNTY TENNESSEE STUDY AREA

	Hydrocarbon Emissions (tons/year)					
	County					
Emission Source	Davidson	Rutherford	Sumner	Williamson	Wilson	Total
Surface Coating	974.5	525.7	53.3	162.5	110.9	1,826.9
Dry Cleaning	433.9	64.5	66.0	41.8	41.5	647.7
Gasoline Marketing	2,387.6	355.1	363.9	220.3	228.0	3,554.9
Degreasing	-	140.5	-	39.6	110.7	290.8
Rubber Processing	567.6	181.5	-	-	-	749.1
Petroleum Storage	2,799.9	37.1	-	3.8	-	2,840.8
Graphic Arts	523.8	60.5	3,886.1	44.5	-	4,514.9
Chemical Processing	1,230.7	-	-	-	-	1,230.7
Fuel & Refuse Burning	475.1	88.2	729.2	167.2	80.1	1,539.8
Cutback Asphalt	-	46.7	46.7	46.7	46.7	186.8
Hot Mix Asphalt	-	1.0	-	0.1	-	1.1
Miscellaneous Solvent Uses	282.7	6.1	2.8	-	-	291.6
TOTAL	9,675.8	1,506.9	5,148.0	726.5	617.9	17,675.1
Percent of Total by County	55.0	8.5	29.0	4.0	3.5	

TABLE 3-2. HYDROCARBON EMISSIONS IN THE STUDY AREA BY SOURCE CATEGORY

Emission Source	Hydrocarbon Emissions (tons/yr)		Percent of Total		Number of Point Sources with Emissions > 25 tons/yr	Percent of Total Emissions from Major Point Sources
	Baseline	1977	Baseline	1977		
1. Graphic Arts	4,515	*	25	22	3	88
2. Gasoline Marketing	3,555	*	20	17	None	0
3. Tank truck loading at Gasoline Bulk Terminals	2,841	2,959	16	14	14	100
4. Surface Coating	1,827	*	10	9	21	78
5. Fuel and Refuse Burning	1,540	*	9	7	4	47
6. Chemical Processing	1,231	4,380	7	21	1	100
7. Rubber Processing	749	806	4	4	2	100
8. Industrial & Commercial Dry Cleaning	648	*	4	3	None	0
9. Degreasing	291	*	2	1	3	75
10. Other (Miscellaneous solvent uses; hot mix asphalt plants, cut-back asphalt)	480	*	3	2	None	0
TOTAL	17,677	21,000	100	100		

*Information on 1977 emissions unavailable, assumed equal to baseline emissions other data about major and minor point sources are described in more detail in these sections.

The baseline inventory is based directly on data supplied by the local agencies with several additions. A change was made in the gasoline marketing emissions as reported in the literature.[5] A more current emission factor for gasoline stations was used to adjust the emission rates. This change is discussed in Section 5.

Emissions from the use of cutback asphalt were added to the baseline inventory. Statewide total emissions from cutback asphalt were 4670 tons in 1975.[6] It was assumed that 4% (187 tons/year) of the total emissions occur in four counties in the study area and none occur in Davidson County. The latter assumption is based on the fact that cutback asphalts are used mainly for winter patching in rural areas where there is limited access to hot mix asphalt plants.

3.4 Current and Future Emissions

The inventory in Table 3-1 represents 1975 data, so it does not provide current emission estimates. More recent information indicates increased emission rates for several categories. In Davidson County, current data show:

- increase in rubber processing emissions at company RP-2 from 568 to 625 TPY
- increase in petroleum storage tank emissions from 2800 to 2959 TPY
- increase in chemical processing emissions at company OC-1 from 1230 to 3411 TPY.

Fugitive emissions from operations at company OC-1's dimethyl terephthalate plant were estimated and included in the 1977 data reported in Table 3-2. Only process emissions were reported in the information sources available for this study. Fugitive emissions were estimated at 0.2 percent of plant throughput, assuming process emissions of 3411 tons/year were 0.7% of plant throughput.[7]

In Sumner County, company GA-4 currently has 2 presses in operation with 2 more under construction. The estimated emission rate will increase from 3886 to 8066 TPY after completion of construction.

Data for 1977 emissions are included in Table 3-2.

3.5 References

1. "HC Report." Data supplied by Eddie Barnett, Tennessee Health Department.

2. PEDCo-Environmental Specialists, Inc. Hydrocarbon Area Source Emission Inventory for Cheatham, Davidson, Rutherford, Sumner, Williamson and Wilson Counties, Tennessee. EPA Contract No. 68-02-1375, Task Order No. 9. Cincinnati, Ohio, July, 1976.

3. Environmental Protection Agency. Office of Air Programs. Emissions Inventory Subsystem (EIS), National Emissions Data System (NEDS). Data for Rutherford, Sumner, Williamson and Wilson Counties, 1977.

4. National Business Lists, Inc. Potential Hydrocarbon Sources (Davidson, Rutherford, Williamson, and Wilson Counties). April 1977.

5. PEDCo-Environmental Specialists, Inc. Hydrocarbon Area Source Emission Inventory for Cheatham, Davidson, Rutherford, Sumner, Williamson and Wilson Counties, Tennessee. EPA Contract No. 68-02-1375, Task Order No. 9. Cincinnati, Ohio, July 1976.

6. Kirwan, Francis M., and Clarence Maday. Air Quality and Energy Conservation Benefits from Using Emulsions to Replace Asphalt Cutbacks in Certain Paving Operations. Office of Air Quality Planning and Standards, Environmental Protection Agency. May 1977.

7. Radian Corporation, Control Techniques for Volatile Organic Emissions from Stationary Sources, draft report, DCN 200-187-12-07, EPA Contract No. 68-02-2608, Task 12. Austin, Texas, September 1977.

4.0 HYDROCARBON EMISSIONS FROM THE GRAPHIC ARTS INDUSTRY

4.1 Description of Operations

The graphic arts industry includes operations involved in printing an image onto a surface. The industry can be classified in three general categories: 1) publishing-newspapers, books, magazines; 2) package printing--paper containers, labels; and 3) metal decorating--metal containers, bottle caps, metal signs. These categories differ mainly by the type of surface printed.[1]

Printing operations vary in method. Direct printing is the transfer of an image directly from an image surface to the print surface; offset printing involves the use of an intermediate surface. Material to be printed may be web-fed to the press from a roll and remain continuous throughout the printing operation, or it may be fed in individual items or sheets.

The five types of printing processes, which vary according to the nature of image surface, are letterpress, flexography, lithography (web-offset), gravure, and screen process printing. The processes are described in Table 4-1, which defines ink characteristics, tells how solvent emissions are produced, and lists industrial applications.

The main source of emissions from printing is the release of ink solvent during drying. Some printing processes use inks which dry without solvent emissions, but web-letterpress and web-offset (lithography) using heat-set inks, flexography, and gravure printing all produce solvent emissions from ink drying. Solvent may also be emitted during ink application in the flexographic and gravure processes. Generally, there is a direct relationship between ink consumption and emission rates.

TABLE 4-1. TYPES OF PRINTING OPERATIONS AND EMISSION CHARACTERISTICS[1,2]

Process	Method of Transferring Image (Direct or Offset)	Feeding Method (Roll or Sheet Fed)	Ink Type and Drying Characteristics	Emissions	Industrial Applications
Letterpress	The image is transferred directly from a raised surface on a cylindrical plate. Ink is applied to the raised image area. It must be viscous enough not to run into the recessed, non-image area.	Sheet fed	Oxidative drying ink contains little solvent and dries by air oxidation at room temperature in racks.	Oxidative drying inks do not produce solvent emissions.	Periodical publication.
		Roll-fed (web letterpress) porous paper (newsprint).	Ink is made of carbon black and petroleum oils and "dries" by absorption into the porous paper.	Inert ink mist and paper dust collected in room air conditioning system.	Newspaper publishing.
		Roll-fed (web letterpress) non-porous paper.	Heat set ink contains 30-45% solvents. Solvent evaporates in drying tunnel. High speed operations use a petroleum solvent (kerosene or fuel oil boiling range). Low speed operations use an alkyd or vegetable oil solvent which dries slowly by oxidation or polymerization.	Up to 60% of the solvent evaporates in the drying tunnel at around 400°F.	Periodical publication.
Screen Printing	The image area is a fine screen through which ink or paint can be forced. The screen is masked on non-image areas.	Sheet fed.	Water colors are used for printing posters and water-base emulsions are used for fabric. Fast-drying lacquer inks are dried in dryers and drying racks.	Water-based inks produce no significant emissions. Solvent emissions from lacquer inks occur in printing, in the dryer, and at drying racks.	Printing of greeting cards, signs, wallpapers, and textiles.
Flexography	The image is transferred directly from a raised image area on a rubber plate. Used for multicolor printing on a variety of surfaces.	Most are roll-fed (rotary web) presses.	Very fluid (low viscosity) inks containing about 60% solvent. Inks dry by solvent evaporation below 250°F (120°C). Water based inks are used. Steam-set inks are used for printing paper bags.	90% of the solvent is emitted during printing and in dryer exhaust with solvent-based inks. Water-based and steam-set inks produce no significant solvent emissions.	Printing on flexible packaging, milk cartons, bags, folding cartons, corrugated paper, paper cups and plates, labels, envelopes and gift wrap.
Lithography (web-offset)	The image and non-image areas are on the same plane. The image area is ink-wettable and the non-image area is water-wettable. In offset lithography, the image is transferred to a rubber blanket cylinder which prints the image on the substrate. Direct lithography is also used.	Most are web-fed (few are sheet-fed).	Both oxidative drying and heat-set inks are employed. Heat-set inks contain 30-45% hydrocarbon solvents and dry by solvent evaporation at around 400-500°F (200-260°C).	Solvent emissions in dryer exhaust when heat-set inks are used.	Books, pamphlets, metal decorating, newspapers with circulation of over 100,000.
Gravure	The recessed image area engraved on a plate or cylinder is filled with very fluid ink by submerging in an ink bath. After excess ink is wiped from the non-image area using a blade (doctor knife), the image is transferred directly to the substrate.	Sheet-fed gravure is slow and little used. Roll-fed gravure (rotogravure) is more widely used (press speeds up to 2,000 feet per minute).	Inks are very fluid and contain 40-80% solvent, volatile aromatics which evaporate rapidly even at room temperature. Drying occurs in a steam drum or hot air dryer at 38-120°C (100-250°C).	Solvent emissions in dryer exhaust.	Package printing (cellophane, foil, gift wrap, labels) periodicals, catalogues, Sunday newspaper supplement.

4.2 Levels and Sources of Emissions

The study area has an estimated 4500 tons per year of hydrocarbon emissions from the graphic arts industry, about 25 percent of the total 1975 emissions. Table 4-2 lists the sources of hydrocarbon emissions by county and summarizes information about specific printing operations obtained from local files and from contacts with plant personnel. The majority of the emissions (86 percent) are produced by a single rotogravure printing facility, company GA-4 in Sumner County. Three other facilities (two publishing operations and a bag manufacturer) produce another two percent of the emissions, and eleven percent of the emissions are produced by numerous small unidentified printing facilities. These small facilities are classified as area sources and the emissions were estimated based on ink consumption (sales) data for Davidson County.[3] Emissions from one additional printing operation, which employs rotogravure printing to manufacture giftwrap, are controlled using carbon adsorption for solvent recovery. Controlled emissions from this source are about one percent of the total.

Table 4-3 lists the types of printing processes used in the study area and shows the percent of total emissions produced by each. About one percent of the emissions (52 tons/yr) are produced by 2 publishers using web-letterpress or web-offset (lithography). In the absence of specific information, it can be assumed that these emissions occur from drying heatset inks. Oxidative drying inks can also be used in such operations, but no significant hydrocarbon emissions are produced with these inks. These emissions from heatset ink drying are produced at three locations with similar emission rates (17-19 tons/year or about 6 lbs/hr).

TABLE 4-2. 1975 HYDROCARBON EMISSIONS FROM OPERATIONS IN THE STUDY AREA

Emission Source Name and Location	Description of Operation		Hydrocarbon Emissions (tons/year)	Description of Emissions
	Product	Type of Printing Press		
Davidson County				
GA-1 (two locations)	Prints periodicals, telephone directories, and pamphlets	7 offset presses 4 letterpresses	16.6 16.6	It is assumed that these hydrocarbon emissions are solvents from drying heat-set inks.
GA-2	Prints periodicals	2 web-offset (lithographic)	19.1	It is assumed that these hydrocarbon emissions are solvents from drying heat-set inks.
Numerous Small Printing Operations (Area Sources)	Varied, undefined	Varied, undefined	471.5	Based on estimated solvent emissions from the use of printing ink in Davidson County.[3] Emission factor: 2lb organic per gallon of ink used.
Rutherford County				
GB-1	Manufactures polyethylene bread bags	7 flexographic presses	60.0	Emissions are based on solvent and ink consumption in the flexographic printing operation. Inputs are 30 lb/hr solvent and 30 lb/hr ink. Outputs are 20 lb/hr hydrocarbons (about 2/3 of the solvent is emitted). Solvents are mixtures of isopropanol, n-propyl acetate, heptane, and ethanol.
GA-3	Unidentified publications	Undefined	0.5	
Sumner County				
GA-4	Prints commercial catalogues (coated and uncoated paper)	2 rotogravure printing lines (one single color, one multicolor) 10 printing units each	3886.0	Emission estimate is based on solvent consumption assuming that 20% of the solvent is volatile aromatics which evaporate during the printing operations. Solvent is composed of toluene, ethyl-benzene, C_9 and greater naphthenes, and olefins.
GA-5	Unidentified publications	Undefined	0.1	
Williamson County				
GA-6	Manufactures ribbon and giftwrapping paper	4 rotogravure printing lines	(44.5) With carbon adsorption controls	Emissions of toluol and ethyl acetate after solvent recovery using carbon adsorption. The solvent recovery efficiency is around 90%, and the solvent is reused in the process.
		Controlled Emissions	44.5	
		Uncontrolled Emissions	4470.4	
		TOTAL EMISSIONS	4514.9	

TABLE 4-3. PERCENTAGE OF HYDROCARBON EMISSIONS PRODUCED BY TYPE OF PRINTING METHOD IN THE NASHVILLE AREA IN 1975

Printing Process	Uncontrolled Emissions (tons/year)	Percent of Total Emissions
Web Offset (lithography) and Web Letterpress Processes (probably employing heat-set inks)	52.3	1.2
Flexography	60.0	1.3
Rotogravure	3886.0	86.0
Varied, Undefined Small Sources	472.1	10.5
	4470.4	99.0

Another one percent of the emissions (60 tons/yr) are produced in a flexographic process used to print polyethylene bread bags manufactured by company GS-1. The facility has seven presses each with a dryer exhaust rate of 4418 acfm (125°F). Total solvent consumption (probably including some manufacturing steps in addition to printing) is on the order of 2500 gallons per week. Solvent input to the presses is 30 lb/hr, ink input is 30 lb/hr, and volatile organic emissions are 20 lb/hr. The estimated emission rate of 60 tons/year is based on 6240 operating hours per year.

Eighty-six percent of the emissions from the graphic arts industry are produced by company GA-4 in Sumner County. In 1975, 2 press lines were in operation at the 272,000 square foot plant. The single color press line prints 96 pages per revolution, the multicolor press, 48 pages per revolution. Both lines contain 10 printing units each consisting of an ink fed print roller, forced air heated drying oven and induced draft fan. The oven exhaust from all ten printing units (4000 acfm at 150°F) is sent to one stack (40,000 acfm). Printed paper is stacked in a pile and emissions from the paper stack are collected with an induced draft fan and sent to a chilled condenser. Plant personnel reported that a negligible amount of solvent is collected in the condenser.

Company GA-4 prints single- and multi-color commercial catalogues on both coated and uncoated paper. Hydrocarbon emissions are estimated based on ink consumption rates and solvent content of the ink. The solvent is composed of C_6 and greater naphthenes, toluene, ethyl benzene, and olefins. The emission rate of 3886 tons/year is based on the ink consumption rate and the estimate that 20% of the ink solvent (the volatile aromatic components) evaporates in the drying ovens.

4.3 Control Technology

Control methods applicable to the three kinds of printing operations in the study area are summarized in Table 4-4.

Emissions from gravure printing can be controlled by carbon adsorption, incineration, or substitution of water-based inks. As described in Table 4-4, the applicability of these methods depends on the kind of printing operation. All of the uncontrolled emissions from rotogravure printing are produced by company GA-4. Company GA-6 also uses rotogravure printing for giftwrap. Emissions from this printing operation are currently controlled by carbon adsorption.

Carbon adsorption is the method of choice for GA-4's plant, where solvent can be recovered and reused. The company has tested and installed carbon adsorption units at another location and has evaluated the use of carbon adsorption units at the Sumner County plant. Test results for a 90% efficient adsorber treating 120,000 cfm of oven exhaust showed that operating costs would be offset by the value of recovered solvent if solvent cost was $0.65/gallon. Solvent costs at that time were around $0.50/gallon. The company has also tested water-based inks, but the results showed that the quality of the printed product was unacceptable.

Emissions from flexographic printing are produced at one location in the study area, company GS-1. As shown in Table 4-4, either incineration or substitution of water-based ink can be used to reduce solvent emissions from flexography. While water-based inks are now used in some operations, it is not clear whether they would be applicable for printing polyethylene bread bags. Incineration could reduce solvent

TABLE 4-4. SUMMARY OF CONTROL METHODS AVAILABLE FOR HYDROCARBON EMISSIONS FROM PRINTING OPERATIONS IN THE STUDY AREA[2,4,5]

Printing Method	Control Process	Applications and Extent of Use	Rate of Hydrocarbon Emissions (kg volatile organics/ℓ ink used)		Overall Control Efficiency (%)
			Uncontrolled	Controlled	
Rotogravure (ink contains 60% solvent)	Carbon adsorption	Most useful at large publication plants where solvent recovery and reuse is possible	0.5	0.05	90
	Incineration	Packaging and specialty printers where solvent recovery is not feasible	0.5	0.07	85
	Ink substitution (water-borne ink)	Special uses, not available for all applications	-	-	-
Flexography (ink contains 60% solvent)	Incineration (catalytic or direct flame)	Has been used at a few installations	0.36	0.07	85
	Ink substitution (water-borne ink)	Application depends on ability of substrate to absorb aqueous solvent and on drying speed	-	0.1	80
Web letterpress and Web-offset Lithography using heatset ink (45% solvent)	Direct flame incineration (afterburners)	In use at a number of installations	0.36	0.04	90
	Catalytic incineration	Has been tested	0.36	0.06	85
	Ink substitution [heat reactive, thermally catalyzed inks (15-20% solvent)]	Commercially available, some problems in application	-	0.06	85
	Ink substitution (UV curing inks)	Commercially available, will be widely used by 1980	-	0	100

emissions by about 80 percent (overall efficiency) in this application.[4]

As shown in Table 4-4, there are a number of control methods available for emissions from web-offset (lithography) and web-letterpress printing.[4,5] Both processes employ heatset inks containing about 45% solvent. There are three emission sources in the study area using web-offset or letterpress printing: company GA-1 (2 locations) and company GA-2.

The control methods listed for heatset inks in Table 4-4 include both add-on devices (thermal incineration, catalytic incineration) and process change (substitution of thermally catalyzed, low solvent, or UV cured inks).

Thermal incineration is most widely applied in the industry.[4,5] Drying oven exhaust is burned in a direct flame (gas or oil) afterburner at 1100-1500°F (600-800°C). The efficiency of the method is about 95 percent, and overall control efficiency is about 90%.[4] Fuel costs are significant, the major operating expense. Some printers have stopped using existing afterburners during fuel shortages or due to increased fuel costs.[5] Heat exchangers can be employed to recover some of the energy for preheating gas to the drying ovens. With this feature fuel costs can be reduced as much as 70 percent, but equipment costs are higher.

Catalytic incineration employs a flameless oxidation reaction accelerated by a catalyst, usually a platinum or palladium coated ceramic pellet. This method has been tested but does not appear to be as widely applied as thermal incineration. Fuel costs are significantly reduced, and heat exchangers can be employed. Poisoning and thermal deactivation of the catalyst can be a problem.

Carbon adsorption has been used successfully at a large lithographic (web-offset) facility.[5]

Ink substitution appears to be attractive to the web-offset and letterpress industry as a control method. Table 4-5 lists some commercially available inks used in the web-offset industry. Ink cost and fuel requirements of substitute inks are compared to those for conventional heatset inks.[5] Low-smoke, low-solvent, or low-temperature drying inks can be substituted with some increase in ink cost and a decrease in fuel cost. Conventional drying equipment can be used, and reductions in plume opacity and odor have been demonstrated. No information is available about the reduction in hydrocarbon emissions.

Thermally catalyzed (heat-reactive) inks containing about 15 percent solvent can also be used with conventional drying equipment. The ink sets by catalytic heat activated polymerization of nonomers and prepolymers. Heat reactive inks cost 40 to 100 percent more than conventional inks and use fifteen percent more fuel, but added equipment cost is negligible.

UV curing photoreactive inks are set by polymerization or exposure to ultraviolet radiation. They cost 85 to 100 percent more than conventional inks and their use requires the purchase of UV drying equipment. Energy costs are reduced, drying is simplified, the ink does not dry in equipment during shutdowns, and hydrocarbon emissions are eliminated because the ink contains no solvent. Disadvantages are the difficulty of ink removal during paper reclamation, and potential health hazards to workers from UV radiation and skin and eye irritation from the inks. This control method, although considered unconventional and costly, has been characterized by industry representatives as the ideal control method.[5] It is predicted that UV curing inks will be

TABLE 4-5. COMPARISON OF SUBSTITUTE INKS FOR WEB-OFFSET PRINTING WITH CONVENTIONAL HEATSET INKS[5]

Ink Type	Percent solvent	Relative cost	Web temp. (°F)	Relative gas usage	Plume opacity (percent)	Relative odor
Heatset	40-45	100	300	100	15-20	100
Low-smoke	40-45	105	300	100	10-15	60
Low-solvent	25-30	120	270	85	5-10	40
Unspecified low-temp. drying ink	45-50	150	210	60	10-25	35
Low-temp. drying ink (xerox)	25-30	125	230-250	60	15-20	slight
Low-temp. drying ink (Richardson Ink Co.)	25-30	105-110	220-250	87	none	slight
Heat-reactive	0-15	140-200	340	115	0-5	20
UV cure	0	200-300	120	0	0	trace

employed in 70% of letterpress operations and 80% of web-offset operations by 1980.[1]

Table 4-6 summarizes the control methods which appear to have the best applicability for emission sources in the study area. Overall control efficiencies published in the literature[4] are used to estimate potential reductions in hydrocarbon emissions.

4.4 Control Cost and Cost Effectiveness

Cost data are available for carbon adsorption and thermal incineration at rotogravure facilities and catalytic and thermal incineration at web-offset operations.[1] The data are for model installations in the approximate size range of the facilities in the study area. Cost data for incineration in flexography operations and UV curing in web-offset or letterpress operations are not available. Control costs and cost effectiveness for model rotogravure and web-offset operations are given in the following sections 4.4.1 and 4.4.2.

4.4.1 Costs for Carbon Adsorption in Rotogravure Printing

Published cost data were used to compare the cost effectiveness of carbon adsorption and thermal incineration with heat exchange. The carbon adsorption system with recovered solvent valued at 4¢/lb (1970 value) was found to have the higher cost effectiveness. Table 4-7 compares the operating conditions for a model plant for which carbon adsorption capital and operating costs were calculated to conditions at company GA-4's plant. The model small plant described in Table 4-7 has twice the number of printing lines and the hydrocarbon emission rate appears to be twice that of GA-4's, but the gas rates to the adsorber are

TABLE 4-6. IDENTIFICATION OF APPLICABLE CONTROL METHODS AND RESULTING REDUCTIONS IN HYDROCARBON EMISSIONS FROM PRINTING OPERATIONS IN THE STUDY AREA

Emission Source	Uncontrolled Emission Rate (tons/yr)	Control Method	Overall Efficiency[a] (%)	Hydrocarbon Emissions After Application (tons/yr)
Rotogravure (GA-4)	3886	carbon adsorption	90	390
GA-6	(44.5) controlled	carbon adsorption (in use)	-	44
Flexography (GS-1)	60	incineration	85	9
Web-Offset and Letter-press (GA-1 and GA-2)	52	1. catalytic incineration	85	0-8
		2. UV curing ink	100	
Area sources (undefined)	472	none specified	-	472
	4415 tons/year			915-923 tons/year

[a] Reference 4

TABLE 4-7. COMPARISON OF OPERATING CONDITIONS FOR MODEL PLANT AND EXISTING ROTOGRAVURE PLANT

Plant Specifications and Operating Conditions	Company GA-4,[a] Sumner County	Model Small[b] Plant
Number of Press Lines	2 (10 units each)	4 (No. of units not specified)
Exhaust rate (acfm) for each press line	40,000	12,450
Conditions at Adsorber Inlet:		
Gas Rate (acfm)	80,000	49,800
Temperature (°F)	150	90
Gas Rate (scfm)	68,200	48,000
Solvent Concentration (% LEL)	20	35
Solvent Concentration (ppm by vol)	unknown	3,560
Solvent Emissions (lb/hr)	1,245[a]	2,484

[a] Data obtained during plant visit on 26 September 1977 and from communications with plant engineering manager. The solvent emission rate in lb/hr was calculated based on 6240 operating hours/year from an annual estimate of 3886 tons/year. The annual estimate is 20% of total solvent consumption.

[b] Data obtained from Reference 1.

similar. The GA-4 emission rate was estimated from ink solvent aromatic content (20%) and annual solvent or ink consumption. Since details are unavailable, it is not clear whether this total annual emission rate provides an accurate description of the actual hourly oven exhaust rate. Rotogravure inks usually contain about 60% solvent, and about 60 percent of the solvent is typically emitted in the oven exhaust.[1] However, large variations in emission rates occur depending on press speed, number of colors and sides printed, ink coverage, web width, and type of paper (coated or non-coated). The model plant emission rates are probably based on actual concentrations in the oven exhaust.

In summary, the model plant may not be entirely representative of conditions at the GA-4 plant. Cost effectiveness calculated on the basis of annual cost (credit) and tons of hydrocarbons controlled will be higher for the model plant than for GA-4. Capital cost estimated from gas flow rate to the absorber would be similar for the two plants.

Capital and operating costs and calculated cost effectiveness for the model small plant and a larger plant are summarized in Table 4-8. Published data[1] were converted to 1977 dollars and capital charges were increased to 17.2% of capital as described in footnote b.

4.4.2 Costs for Catalytic Incineration in Web Offset (Lithographic) Printing

Published cost data for both thermal and catalytic incineration for model web-offset printing operations showed that catalytic incineration had the higher cost effectiveness. The exhaust rates for the model plants were too low to justify the use of heat exchange equipment.

TABLE 4-8. CAPITAL COST, NET ANNUALIZED COST, AND COST EFFECTIVENESS FOR CARBON ADSORPTION CONTROLS AT TWO MODEL ROTOGRAVURE PRINTING FACILITIES[1]

Cost Items and Specifications	Model Small plant (4 presses)	Model Large plant (12 presses)
Effluent Gas Rate, SCFM	48,000	144,000
Capital Cost ($1,000)	676.2	1,461.2
Direct Operating Cost ($1,000/yr)[a]	183.4	507.9
Capital Charges ($1,000/yr)[b]	116.3	251.3
Solvent Credit ($1,000/yr)[c]	(1,216.0)	(3,680.0)
ANNUAL COST (Credit) ($1,000/yr)	(916.3)	(2,920.8)
Uncontrolled emissions (tons/yr)[d]	9936	28,808
Control Efficiency (percent)	95	95
COST EFFECTIVENESS ($1,000/ton)	(0.10)	(0.11)

[a] Includes operating labor, maintenance and repair, and utilities.

[b] Includes depreciation, interest, administrative overhead, property taxes, and insurance calculated @ 10% for 15 years plus 4% for taxes, insurance and administration

[c] Solvent credited at 4¢/lb (1970 figure); total credit inflated to 1977.

[d] Based on 8000 operating hours/year. Hourly rates are 2484 and 7452 lb/hr.

Model plant operating conditions and specifications are listed in Table 4-9. Very little information is available describing the three emission sources in the study area that use heatset inks. Annual emission rates are 17-19 tons/year, equivalent to about 5-6 lb/hr on the basis of 6240 operating hours/year. These emission rates are comparable to those of the small model plant. In the absence of data on exhaust gas rate, the hydrocarbon emission rates provide the only basis for concluding that the small plant cost data are applicable to emission sources in the study area.

Capital costs, net annualized costs, and cost effectiveness data are given in Table 4-10.

4.5 Economic Impact of Control Costs

No published information was found concerning the economic impact of control costs for the graphic arts industry.

4.6 References

1. Industrial Gas Cleaning Inst. Air Pollution Control Technology and Costs in Seven Selected Areas, EPA-450/3-73-010. EPA Contract No. 68-02-0289. Stamford, Connecticut, December 1973.

2. Radian Corporation, Control Techniques for Volatile Organic Emissions from Stationary Sources, DCN 200-187-12-07, EPA Contract No. 68-02-2608, Task 12. Austin, TX., September 1977.

TABLE 4-9. MODEL PLANT OPERATING CONDITIONS AND DESIGN BASIS FOR CATALYTIC INCINERATOR CONTROLS AT WEB-OFFSET (LITHOGRAPHIC) PRINTING FACILITIES[1]

Operating Conditions and Specifications	Model Small Plant	Model Large Plant
Process Conditions		
Effluent Gas Temperature, °F	350	350
Effluent Gas Rate, SCFM	2,000	7,000
Effluent Gas Rate, ACFM	3,060	10,700
Hydrocarbon Concentration, ppm[a]	500-2,000	500-2,000
Hydrocarbon Emission Rate, lb/hr		
Maximum	10.1	35.4
Average	6.3	22.1
Heat of Combustion of Hydrocarbons, Btu/lb[b]	19,500	19,500
Heating Value of Gas, Btu/SCF		
Maximum	1.5	1.5
Average	0.9	0.9
Incinerator Specifications		
Inlet Temperature, °F	350	350
Outlet Temperature, °F	1,100	1,100
Burner Duty, MMBtu/hr	1.89	6.60

[a] Measured as methane equivalents

[b] Assumed as n-hexane

TABLE 4-10. CAPITAL COST, NET ANNUALIZED COST, AND COST EFFECTIVENESS FOR CATALYTIC INCINERATION CONTROLS AT TWO MODEL LITHOGRAPHIC (WEB-OFFSET) PRINTING FACILITIES[1]

Cost Items and Specifications	Model Small Plant	Model Large Plant
Effluent Gas Rate, SCFM	2,000	7,000
Capital Cost ($1,000)	46.8	79.9
Direct Operating Cost ($1,000/yr)[a]	13.9	42.1
Capital Charges ($1,000/yr)[b]	8.0	13.7
Solvent Credit ($1,000/yr)[c]	0	0
ANNUAL COST (CREDIT) ($1,000/YR)	21.9	55.8
Uncontrolled Emissions (tons/yr)[d]	12.6	44.2
Control Efficiency (percent)	95.0	95.0
COST EFFECTIVENESS ($1,000/TON)	1.8	1.3

[a] Includes operating labor, maintenance and repair, and utilities.

[b] Includes depreciation, interest, administrative overhead, property taxes, and insurance calculated @ 10% for 15 years plus 4% for taxes, insurance, and administration.

[c] Solvent credited at 4¢/lb (1970 figure); total credit inflated to 1977.

[d] Annual rate based on average hourly emission rate and 4000 operating hours/year. Hourly rates are 6.3 lb/hr (avg) and 10.1 lb/hr (max) for small plant and 22.1 lb/hr (avg) and 35.4 lb/hr (max) for large plant.

3. PEDCo - Environmental Specialists, Inc. *Hydrocarbon Area Source Emission Inventory for Cheatham, Davidson, Robertson, Rutherford, Sumner, Williamson and Wilson Counties, Tennessee*. EPA Contract No. 68-02-1375, Task 9, Cincinnati, Ohio, July 1976.

4. Environmental Protection Agency, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards. *Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds*. Research Triangle Park, North Carolina. May 1977.

5. *Environmental Aspects of Chemical Use in Printing Operations, King of Prussia, PA, September 1975, Conference Proceedings*. EPA Contract No. 68-01-29-28, Washington, D.C., January, 1976.

5.0 HYDROCARBON EMISSIONS FROM GASOLINE MARKETING

5.1 Description of Operations

Gasoline marketing is defined for this study as the movement of gasoline to and through service stations. It involves supplying the station with gasoline and dispensing the fuel to vehicles. To provide an adequate supply of gasoline, service stations have underground storage tanks from which the gasoline is pumped into the vehicles. These tanks are refilled as needed. Hydrocarbon emissions are produced in two ways; one while bulk gasoline is dropped into the storage tanks, the other during vehicle refueling. Table 5-1 lists some typical emission factors for service stations.

TABLE 5-1. HYDROCARBON EMISSIONS FROM GASOLINE MARKETING OPERATIONS[2]

Emission Source	Hydrocarbon Emission Factors (lb/1000 gallon throughput)
Filling Underground Tank	
Submerged filling	7.3
Splash filling	11.5
Underground Tank Breathing	1
Vehicle Refueling Operations	
Displacement losses	9
Spillage	0.7

A major source of organic vapor emissions is the filling of underground gasoline storage tanks at service stations. Gasoline is delivered to service stations in tank trucks. Emissions are generated when hydrocarbon vapors in the underground storage tank are displaced by gasoline loaded into the tank. The quantity of emissions depends on the method of filling, the tank configuration, and gasoline properties such as temperature, vapor pressure, and composition. An average emission rate for submerged filling (gasoline enters at the bottom of the tank) is 7.3 lb/1000 gallons of gasoline transferred. The average emission rate for splash filling (top entry) is 11.5 lb/1000 gallons transferred. If 50 percent of the underground tanks in the Nashville area were filled by submerged filling, the emissions factor for underground tank filling would be 9.4 lb/1000 gallons of gasoline transferred.

Another source of hydrocarbon emissions is underground tank breathing. Breathing losses occur daily due to gasoline evaporation, primarily from changes in temperature. An average loss through breathing is 1 lb/1000 gallons throughput.

Vehicle refueling emissions occur from spills and when vapors are displaced from the automobile tank by dispensed gasoline. The quantity of displaced vapors is dependent on gasoline temperature, auto tank temperature, relative vapor pressure of the gasoline, and dispensing rates. Although several correlations have been developed to estimate losses due to displaced vapors, significant controversy exists concerning these correlations. It is estimated that the emissions due to vapors displaced during vehicle refueling average 9 lbs/1000 gallons of dispensed gasoline. The quantity of spillage loss is difficult to define, but on the average has been estimated to be about 0.7 lb/1000 gallons of dispensed gasoline.[1]

With the assumption of some 50 percent submerged filling, the emission factor for Nashville area gasoline stations would be 20.1 lb/1000 gallons throughput.

5.2 Levels and Sources of Emissions

The Nashville area has an estimated 3,550 tons/yr of hydrocarbon emissions from gasoline marketing, accounting for approximately 20% of the total emissions. These emissions were estimated using an emission factor and gasoline consumption data. Previously published emission rates were based on an emission factor of 19.0 lb/1000 gallons throughput.[3] In this work, emission rates were adjusted to reflect the emission factor of 20.1 lb/1000 gallons throughput. Based on the emission factors, about 47 percent of the emissions (1670 tons) can be attributed to bulk gasoline drops and 53 percent (1880 tons) to vehicle refueling.

There are 601 service stations in the study area. The number of stations was estimated from a 1977 National Business List. Table 5-2 shows how the total of 601 stations is distributed in the 5-county study area. The average hydrocarbon emission rate per station is 5.9 tons per year, but there are all sizes of stations in the study area. There are ten service stations in Davidson County producing an estimated 10 tons/yr or greater hydrocarbon emissions.

TABLE 5-2. DISTRIBUTION OF GASOLINE STATIONS IN THE FIVE-COUNTY STUDY AREA

County	Number of Gasoline Stations
Davidson	375
Rutherford	73
Sumner	55
Williamson	50
Wilson	58

5.3 Control Technology

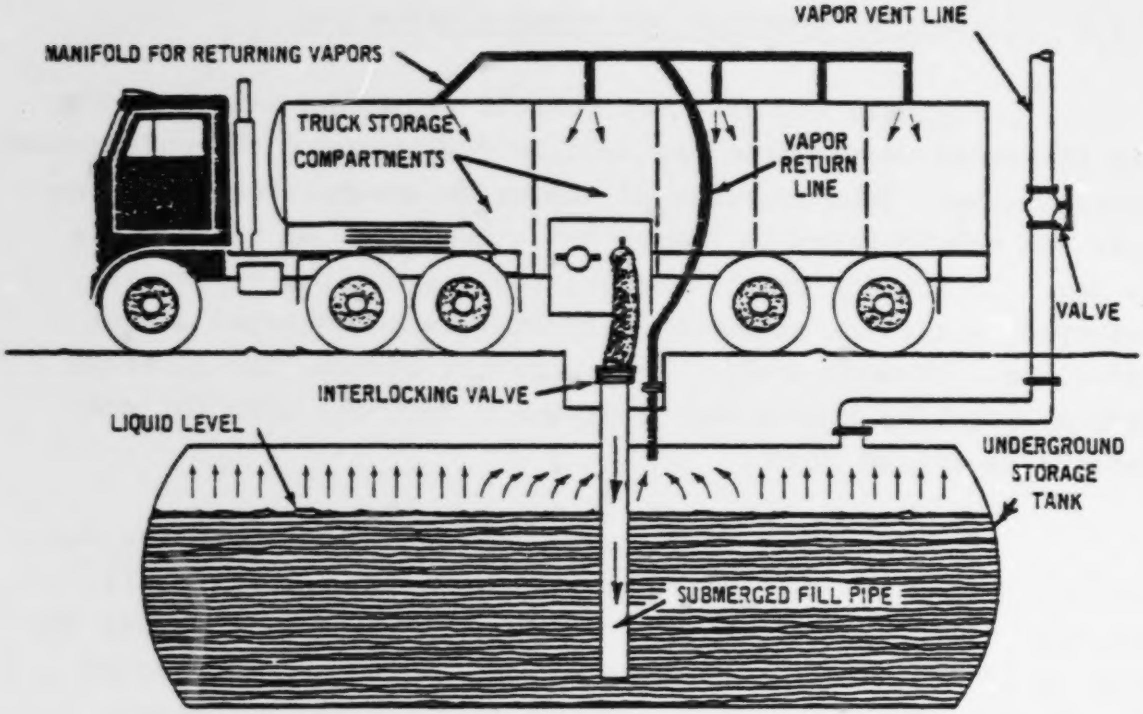
Controls for gasoline station emissions have been designated as Stage I for bulk drop operations and Stage II for vehicle refueling operations. Both types of control involve the recovery of displaced vapors.

5.3.1 Stage I Controls for Bulk Drop Operations

Stage I controls involve using submerged filling and the vapor balance system during the filling of underground storage tanks. A submerged fill pipe is used to discharge a load of gasoline below the surface of liquid in the underground tank. Submerged loading eliminates vaporization caused by the free fall of gasoline droplets from discharging the gasoline at the top of the tank. A fill pipe should extend to within 6 inches of the bottom of the tank.[4]

The vapor balance system involves the collection by the tank truck of displaced vapors from the underground tanks during unloading operations. Figure 5-1 shows a tank truck using a vapor balance system during unloading of gasoline at a service station. The [illegible] vapors are ultimately displaced to a vapor recovery [illegible] the bulk terminal when the tank trucks are filled.

Assuming that some stations in Nashville have submerged fill tanks, Stage I controls can treat about 47 percent of the hydrocarbon emissions from gasoline service stations. The control efficiency of a balance system has been estimated at 93 to 100 percent. Hydrocarbon emissions from underground tank filling operations at a service station using submerged



VAPOR VENT LINE
MANIFOLD FOR RETURNING VAPORS
TRUCK STORAGE
COMPARTMENTS
VAPOR RETURN LINE
VALVE
INTERLOCKING VALVE
LIQUID LEVEL
UNDERGROUND STORAGE TANK
SUBMERGED FILL PIPE

Figure 5-1. Tank truck employing "vapor balance" form of hydrocarbon control during filling underground storage tank.

filling and the vapor balance system are expected not to exceed 0.3 lb/1000 gallons of gasoline transferred.[1]

5.3.2 Stage II Controls for Vehicle Refueling

Stage II controls for vehicle refueling emissions convey displaced vapors from the vehicle fuel tank to the underground storage tank. This transfer of vapors is accomplished with the hose and nozzle shown in Figure 5-2. Two types of systems are in use. In the "balance" vapor control system the vapors are conveyed by natural pressure differentials established during refueling. "Vacuum assist" vapor control systems use a vacuum pump to transfer vapors and a secondary recovery unit for condensing recovered vapors.

Balance system recovery efficiency depends on the collection efficiency at the interface between the gasoline dispensing nozzle and the vehicle fill pipe. 1975 tests showed the control efficiency of the vapor balance system using advanced nozzle designs was near or above 90%, and control efficiency achievable with commercially available nozzles was 85%.[6] Vacuum assist system recovery efficiency depends on two factors, the collection efficiency at the nozzle-fill pipe interface and maintenance-dependent operating reliability of the secondary recovery unit. Field observations of operating units made in 1975 indicated about 75% average availability of secondary recovery units. The overall reduction efficiency of vacuum assist systems is estimated at about 90%.[6]

5.3.3 Reductions in Hydrocarbon Emissions Using Stage I and II Controls

Table 5-3 shows the reductions in hydrocarbon emissions from gasoline stations in the study area that can be achieved with

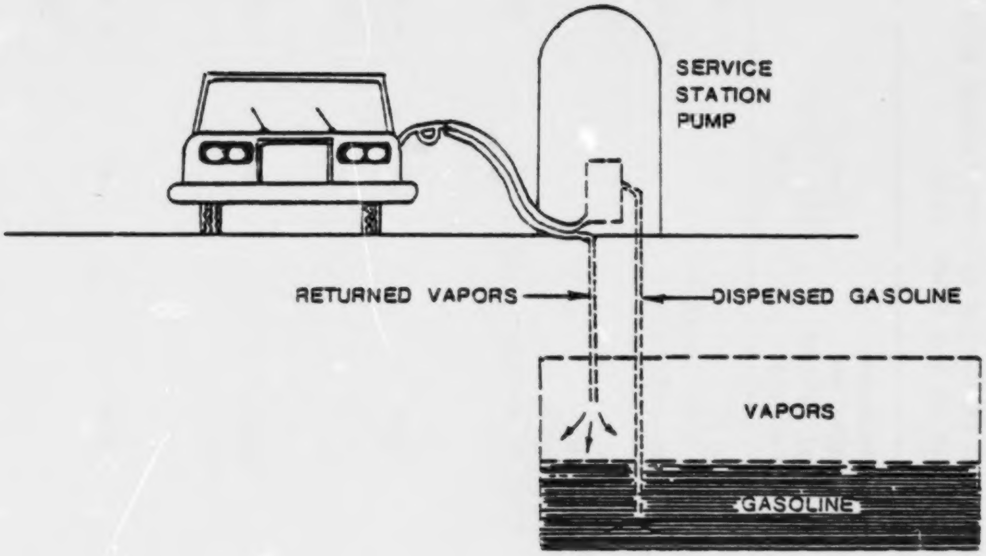

SERVICE
STATION
PUMP
RETURNED VAPORS
DISPENSED GASOLINE
VAPORS
GASOLINE

Figure 5-2. Vapor return system for Stage II controls on vehicle refueling emissions.

TABLE 5-3. CONTROL METHODS AND REDUCTION OF HYDROCARBON EMISSIONS FROM GASOLINE MARKETING OPERATIONS IN THE STUDY AREA

Control Method	Emissions Treated by Control Method (tons/yr)	Control Efficiency (%)	Emission Rate After Controls (tons/yr)
Stage I Controls (submerged fill plus vapor balance for storage tank loading)	1670 (47% of 3550 tons/yr total emissions)	95	84 (emissions after Stage I controls) +1880 (untreated refueling emissions) 1964
Stage II Controls (vapor balance for vehicle refueling)	1880 (53% of total)	85	282 (emissions after Stage II controls)
plus			
Stage I Control (submerged fill plus vapor balance for storage tank loading)	1670	95	+ 84 (emissions after Stage I controls) 306
Stage II Controls (vacuum assist for vehicle refueling)	1880	90	188 (emissions after Stage II controls)
plus			
Stage I Controls (submerged fill and vapor balance for storage tank loading)	1670	95	+ 84 (emissions after Stage I controls) 272

various combinations of Stage I and II controls. Stage I controls can be applied to emissions from storage tank loading (1670 tons/year). Vehicle refueling emissions (1880 tons/yr) will remain uncontrolled. Total emissions after application of Stage I controls would be 1964 tons/year. While Stage I controls are 95% efficient, they provide a 45% reduction in total emissions since they treat only 47% of the total emissions.

Using a combination of Stage I controls and vapor balance for vehicle refueling (Stage II controls), remaining emissions would be about 300 tons/year, a 90% reduction in total emissions. With vacuum assist for Stage II instead of vapor balance, remaining emissions would be 270 tons/year for a 94% reduction in total emissions.

5.4 Capital and Operating Cost

The capital and operating costs have been estimated for retrofit Stage I and II controls at a model 7-pump service station dispensing about 384,000 gallons per year. Stage I control efficiency is assumed to be 95 percent. For a Stage II balance system, a conservative control efficiency of 85 percent was assumed. For a vacuum assist system, 90 percent efficiency is applied. Table 5-4 shows capital costs for Stage I and II controls in 1977 dollars. Costs for Stage I and II controls are shown separately. In practice, Stage II controls would not be applied without Stage I controls. The capital cost for applying both Stage I and II controls is less than the sum of the separate capital costs. Capital costs for Stage I include about $500 for installed hardware (pipes and vents) and about $1400 for trenching, paving, and backfill for vapor return line installation. Some savings on trenching costs would occur if Stage I and Stage II controls were installed simultaneously.

TABLE 5-4. STAGE I AND II CONTROL COSTS FOR A TYPICAL SERVICE STATION DISPENSING 384,000 GALLONS/YR[5,6]

	Stage I	Stage II	
		Balance System	Vacuum Assist System
Capital Cost	$1,900	$6,600	$14,850
Direct Operating Cost[a] ($/yr)	Neg.	330	1,320
Capital Charges[b] ($/yr)	326	1,132	2,545
Gasoline Credit[c] ($/yr)	(372)	(261)	(268)
Annual Cost ($/yr)	(46)	1,201	3,597
Uncontrolled emissions[d] (tons/yr)	2.2	1.7	1.7
Control efficiency (%)	95	85	90
Cost Effectiveness ($1000/ton controlled)	(0.02)	0.83	2.35

[a] Includes labor and materials for maintenance and repair and electricity.
[b] Includes depreciation, interest, administrative overhead, property taxes, and insurance. Calculated @ 10% for 15 years + 4% for taxes, insurance, and administration.
[c] Gasoline credited at 55¢/gallon.
[d] Calculated using emission factor for splash loading.

5.5 Economic Impact of Control Costs

The economic impact of implementing Stage I and II controls depends to some degree on who incurs the cost of the control equipment. As of 1975, about 50% of the gasoline stations in the U.S. were owned by major oil firms, 20% were owned by large integrated marketers and regional refiners, and 30% by small businessmen -- jobbers and dealer/owners. These small businessmen would be most affected by the implementation of controls.[7]

Stage I controls require a relatively small capital investment and for larger stations the annual capital charges may be offset by the recovered gasoline credit. These controls may provide a positive yearly cash flow for larger stations.

The economic impact of implementation of Stage II controls would be much greater. Oil companies, integrated marketers and regional refiners could use their holdings as collateral for loans, use internal funds, or sell off marginal outlets. Jobbers and dealer/owners, however, would have to rely on more expensive sources of funds such as banks or private investors. The Small Business Administration could be of some help but could not loan the entire amount. Large jobbers would be above the SBA size limits and would need more money than many banks would be willing to lend.

In addition to those retailers forced out of business because of lack of capital, others will either be unable to compete if costs are passed through to customers or unable to absorb costs which are not passed through.

The economic impact of Stage II control implementation on oil jobbers has been evaluated in a study for the National Oil Jobbers Council. For jobbers owning their own marketing facilities which require vapor controls, the installation of vapor balance and vacuum assist controls will cost an amount equivalent to 28.4 percent of their net worth. Furthermore, it would be those jobbers with the least economic flexibility (lowest net worth) who would be hardest hit by the cost of implementing these controls as shown in Table 5-5. It is estimated that a significant portion of the jobbers fall into the least flexible group.[8]

TABLE 5-5. ECONOMIC IMPACT ON OIL JOBBERS OF IMPLEMENTING STAGE II CONTROLS[7]

Jobber Classification by Net Worth, $	Number of Jobbers in Group	% of Study Group	Average Cost of Vapor Control as Percentage of Net Worth
2MM	15	12	12.6%
700M-2MM	31	24	18.8%
350M-700M	25	19	26.1%
0-350M	59	45	31.7%

Any estimate of the number of stations forced to close as a direct result of Stage II control regulations is complicated by the fact that most of them would be forced to close sooner or later anyway because of their low volume throughput. However, dealer owned and jobber owned stations would suffer more because of their unfavorable financial sources. Phasing in the controls could ease this plight to a certain extent.

According to a national survey, 2% of stations will close as a direct result of control costs if Stage II controls are required and competitive pass-through is allowed. Two percent will close if hybrid systems are required and 4% if vacuum assist systems are required. About two thirds of these closures would be dealer owned or jobber owned outlets. Larger company stations would face potential closure only if cost pass-through were not allowed.[7]

5.6 References

1. Radian Corporation. Control Techniques for Volatile Organic Emissions from Stationary Sources. DCN 200-187-12-07, EPA Contract No. 68-02-2608, Task 12. Austin, TX. September 1977.

2. Burklin, Clinton E., et al. Revision of Evaporation Hydrocarbon Emission Factors. Radian Corporation. Austin, TX. August 1976.

3. PEDCo-Environmental Specialists, Inc. Hydrocarbon Area Source Emission Inventory for Cheatham, Davidson Robertson, Rutherford, Sumner, Williamson and Wilson Counties, Tennessee. EPA Contract No. 68-02-1375, Task Order No. 9. Cincinnati, Ohio. July, 1976.

4. Burklin, Clinton E., et al. Study of Vapor Control Methods for Gasoline Marketing Operations, 2 vols. Austin, TX. Radian Corporation. May, 1975.

5. Environmental Protection Agency, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards. Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. Research Triangle Park, North Carolina. May 1977.

6. Burklin, C.E., et al. Cost Effectiveness of Hydrocarbon Vapor Emission Reduction Methods for Vehicle Refueling Operations at Service Stations. Radian Corporation. Austin, TX. October 1975.

7. Arthur D. Little, Inc. Economic Impact of Stage II Vapor Recovery Regulations: Working Memoranda. EPA Contract No. 68-02-1349, Task 11. Cambridge, Massachusetts. November, 1976.

8. Cavanaugh, E.C., P.S. Dzierlenga, and C.T. Shelton. Potential Economic Impact of Stage II Vapor Control Regulations on Oil Jobbers. Final Report. Radian Project No. 200-124. Radian Corporation. Austin, TX. December 1975.

6.0 HYDROCARBON EMISSIONS FROM GASOLINE STORAGE (TANK TRUCK LOADING) AT BULK TERMINALS

6.1 Description of Operations

Gasoline is distributed from refineries to intermediate storage and loading facilities by pipeline and tank truck. If the intermediate station is supplied by pipeline, it is called a bulk terminal. A bulk plant is supplied by tank truck. All of the storage facilities in Davidson County are pipeline terminals. The major sources of hydrocarbon emissions at bulk terminals are storage tank losses, fugitive emissions (leaks) and tank truck loading operations. Emissions from storage tanks are relatively minor in the Nashville area. Eighty-four percent of the storage tanks in Davidson County have floating roofs which have minimal emissions. Fugitive emissions are considered minor. Therefore, these two sources of emissions will not be addressed. Loading operations are the largest source of emissions and the most adaptable to control measures. This discussion is limited to the sources and control of emissions from loading operations.

Tank truck loading emissions occur as hydrocarbon vapors in empty trucks are displaced by the gasoline loaded into the truck. The vapors displaced from the truck are composed of 1) vapors formed in the empty truck by evaporation of residual product from the previous haul, and 2) vapors generated as gasoline is loaded into the truck. The quantity and composition of the vapor losses are affected by:[1]

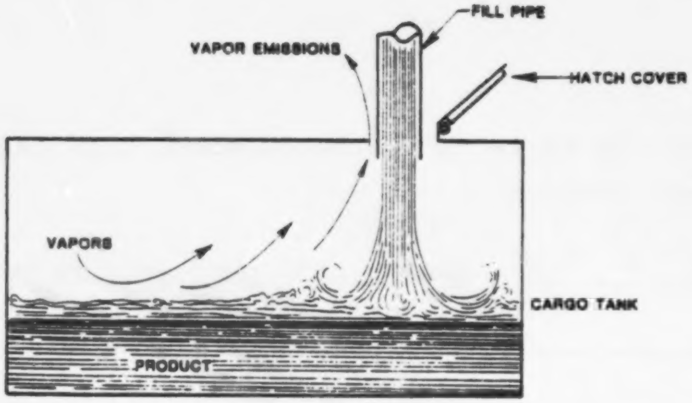
1) method of loading gasoline,
2) ambient temperature,
3) loading rate, and
4) vapor pressure of gasoline.

Methods of loading cargo carriers are shown in Figure 6-1. In the splash loading method, the fill pipe dispensing the cargo is only partially lowered into the cargo tank. Turbulence and vapor-liquid contacting during the splash loading cause high levels of vapor generation and loss. If the turbulence is high enough, liquid droplets will be entrained in the vented vapors.[2]

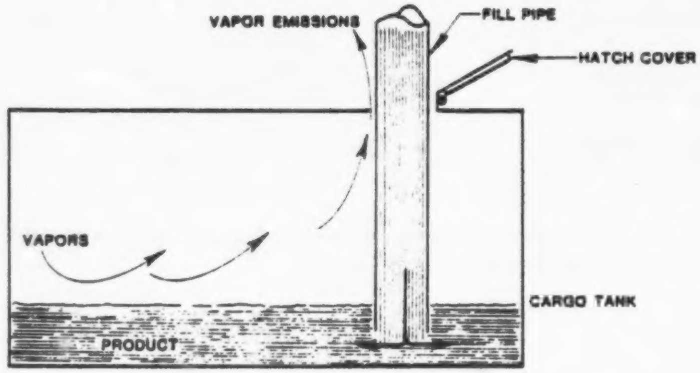
A second method of loading is submerged loading. The two types of submerged loading are the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe descends almost to the bottom of the cargo tank. In the bottom loading method, the fill pipe enters the cargo tank from the bottom. During submerged loading the fill pipe opening is below the liquid level, and liquid turbulence and vapor-liquid contact are reduced. Submerged loading produces lower vapor losses than splash loading.[2]

6.2 Levels and Sources of Emissions

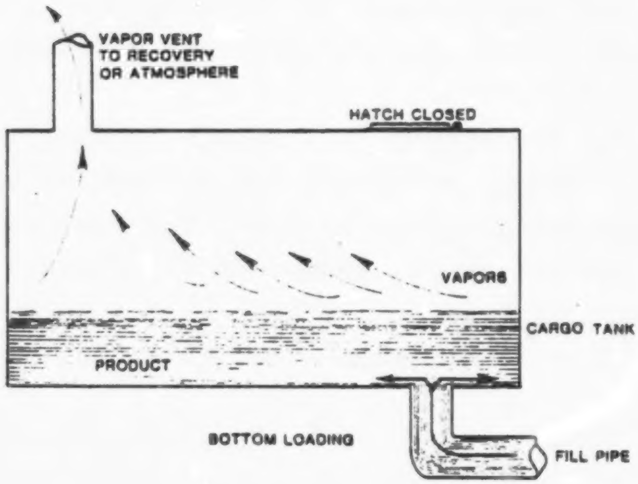
The Nashville area has an estimated 2840 tons/yr of hydrocarbon emissions from bulk gasoline and petroleum storage facilities, approximately 16 percent of the total emissions. The emission figures include emissions from tank truck loading and storage tank working and breathing losses. Storage tank losses were assumed negligible since 84 percent of the storage tanks in Davidson County have floating roofs. The type and number of loading racks and arms are not known for these facilities. None of the facilities have vapor recovery systems. Table 6-1 lists the emission sources by county. The 13 storage facilities in Davidson County produce 99 percent of the emissions. All of these facilities are pipeline terminals and 43 of the 53 storage tanks are equipped with floating roofs. Table 6-2 lists 1977 hydrocarbon emissions from the 13 Davidson County terminals. As


FILL PIPE
VAPOR EMISSIONS
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

SPLASH LOADING


VAPOR EMISSIONS
FILL PIPE
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

SUBMERGED FILL PIPE


VAPOR VENT
TO RECOVERY
OR ATMOSPHERE
HATCH CLOSED
VAPORS
CARGO TANK
PRODUCT
FILL PIPE

BOTTOM LOADING

Figure 6-1. Three methods of loading cargo carriers.

shown in the table, 6 of the 10 fixed roof tanks are located at one small terminal.

TABLE 6-1. 1975 HYDROCARBON EMISSIONS FROM BULK STORAGE OF PETROLEUM PRODUCTS IN THE STUDY AREA

Emission Source	Number of Storage Tanks	Total Hydrocarbon Emissions (tons/yr)
Davidson County		
13 Gasoline Bulk Terminals (See Table 6-2)	53 (10 fixed roof)	2,800
Rutherford County		
Company GB-1*	Unknown	37
Williamson County		
Company GB-2*	Unknown	4
TOTAL		2,841

*Gasoline and some fuel oil storage

6.3 Control Technology

The control technologies applicable to bulk gasoline terminals include changes in the method of loading trucks and add-on vapor collection and recovery systems.

By converting from splash loading to submerged fill or bottom loading, emissions can be reduced by about 58 percent.[3] By allowing the gasoline to enter the tank below the liquid surface, the excess vapors generated by splash loading are eliminated. Cost analysis has proven that submerged fill is more cost effective than bottom loading for the retrofit situation.

Vapor collection and recovery systems can provide additional controls for bulk terminals. In a typical tank truck

TABLE 6-2. 1977 HYDROCARBON EMISSIONS FROM 13 BULK GASOLINE TERMINALS IN DAVIDSON COUNTY

Terminal Number	Number of Storage Tanks		1977 Hydrocarbon Emissions (tons/yr)
	Fixed Roof	Floating Roof	
1	0	5	281
2	0	3	118
3	1	2	148
4	0	7	345
5	0	3	242
6	0	3	129
7	0	4	140
8	0	4	430
9	3	1	243
10	0	2	254
11	0	5	554
12	0	4	49
13	6	0	26
TOTAL	10	43	2959

loading facility, the collected vapors are manifolded to a common header which vents to the vapor recovery system. The vapor recovery system converts the vapors to liquid. Two types of recovery units have been used, the compression-refrigeration-absorption (CRA) unit and the straight refrigeration (RF) system. Cost analysis has shown that the RF system is more cost effective.

The RF system is based on condensation of gasoline vapors by refrigeration at atmospheric pressure. As the displaced vapors are generated, they enter a horizontal fintubed condenser where they are cooled to a temperature of -100°F. The RF system can reduce hydrocarbon emissions by 80 to 93 percent.[1]

Incineration (thermal oxidation) can also be used to control tank truck loading emissions but this method is not as widely applied as vapor recovery systems. Although thermal incinerators have about the same energy requirements as vapor recovery systems, there is no offsetting credit for product recovery, and terminals can rarely utilize waste heat from incinerators. Vapor recovery systems are currently used at some 300 terminals in the U.S., and it is estimated that 10 facilities are equipped with incinerators.[3]

If submerged filling controls (58 percent control efficiency) were used to treat hydrocarbon emissions from tank truck loading at gasoline terminals in the study area, emissions would be reduced from 2840 to 1190 tons/year. With both submerged filling (58 percent reduction) and vapor recovery using the RF system (87% reduction of remaining emissions), emissions would be reduced to about 155 tons per year.

6.4 Capital and Operating Cost

The capital and operating costs and cost effectiveness of the control methods have been estimated for two typical terminal sizes. The terminals are designated as small (25,000 gallons per day throughput) and large (250,000 gallons per day throughput). The recovered gasoline is credited at 35¢ per gallon. Table 6-3 gives the cost information for control methods. The vapor recovery system (93 percent efficient) controls 82 percent of the emissions uncontrolled by submerged fill.

The terminal sizes for which cost data are shown in Table 6-3 are in the same range as the 13 terminals described in Table 6-2 for Davidson County. Emissions from terminals in the study area vary from about 50 tons/year, typical of the small facility, to about 550 tons/year, typical of the large facility.

6.5 References

1. Environmental Protection Agency, Emission Standards and Engineering Division, Chemical and Petroleum Branch. Control of Hydrocarbons from Tank Truck Gasoline Loading Terminals. EPA-450/2-77-026 (OAQPS No. 1.2-082). Research Triangle Park, North Carolina. October, 1977.

2. Radian Corporation. Control Techniques for Volatile Organic Emissions from Stationary Sources. DCN 200-187-12-07. EPA Contract No. 68-92-2608, Task 12, Austin, Texas. September 1977.

TABLE 6-3. CONTROL COSTS FOR TYPICAL GASOLINE BULK TERMINALS[1]

	Submerged Fill		Submerged Fill Plus Vapor Recovery[a]	
	Small	Large	Small	Large
Capital Cost	$ 735	$ 1,575	$72,000	$174,000
Direct Operating Cost[b] ($/yr)	Neg.	Neg.	2,310	6,685
Capital Charges[c] ($/yr)	126	270	12,350	28,890
Gasoline Credit[d] ($/yr)	(3,255)	(32,340)	(1,890)	(19,000)
Annual Cost ($/yr)	(3,129)	(32,070)	12,770	16,575
Uncontrolled Emission (tons/yr)	47[e]	472[e]	19.6[f]	196[f]
Control Efficiency (%)	58	58	82	82
Cost Effectiveness ($1000/ton controlled)	(0.114)	(0.117)	0.795[g]	0.103[g]

[a] Assuming submerged fill and vapor recovery by straight refrigeration.

[b] Includes operating labor, maintenance and repair, and electricity.

[c] Includes depreciation, interest, administrative overhead, property taxes, and insurance. Calculated @ 10% for 15 years + 4% for taxes, insurance, and administration.

[d] Based on proper emission factors, control efficiency, and credit of 35¢ per gallon.

[e] Based on splash loading.

[f] Emissions remaining after application of submerged filling.

[g] Cost effectiveness of submerged fill plus vapor recovery.

3.0 Environmental Protection Agency, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards. Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. Research Triangle Park, North Carolina. May 1977.

7.0 HYDROCARBON EMISSIONS FROM SURFACE COATING OPERATIONS

7.1 Description of Operations

Surface coatings include paints, varnishes, lacquers, stains, shellacs, polymer films, adhesives, waxes, and oils. They can be applied to metal, paper, fabric, wood, glass, stone, concrete, plastic, and other types of surfaces. Basic coating methods include spraying, dipping, flowcoating, and roller coating.[1] Different coating operations require variations and combinations of these methods. Table 7-1 shows the uses of these methods by various industrial surface coating operations.

In the spraying method, the coating is sprayed on the object with the use of a spray gun which is usually operated by compressed air. The spraying area is usually enclosed by a three-sided booth to contain overspray and prohibit dust and particulates from contacting the sprayed surface. A water or oil wash curtain or dry filter may be employed to control sprayed droplets or particulates. The booth is ventilated by a fan to ensure that the concentration of solvent vapors does not reach an explosive level and that the operator is not exposed to dangerous levels of vapors.

Dipping operations involve immersing an object in a dip tank containing the coating. The excess coating on the dipped object is allowed to drain back into the tank. This is accomplished by suspending the object directly over the tank or by using drainboards. To keep the coating mixture uniform, agitation is provided in the tank, usually by circulation of the mixture.

TABLE 7-1. COATING PROCESSES USED BY VARIOUS INDUSTRIAL SURFACE COATING OPERATIONS[2]

Coating Method	Industrial Application
Spray Coat	Auto and light truck Cans (interior, seams) Large appliances (exterior) Wood Furniture Metal Furniture
Dip Coat	Auto and light truck Large appliances (interior) Wire Wood Furniture
Flow Coat	Large Appliances
Roller Coat	Cans (interior, exterior) Coiled metal Paper, film, foil Fabric Flat wood products Adhesives

Flowcoating involves the flowing of the coating in a steady stream over an object suspended from a conveyor line. The excess paint is allowed to drain to a basin and then pumped back to the coating nozzles.

Roller coating operations use machines similar to printing presses. These machines have three or more power-driven rolls. One roll is partially immersed in the coating mixture and transfers coating to a second roll which is parallel to it. The sheets of material are run between the second and a third roll. The material is coated by the transfer of coating from the second roll. The distance between the second and third rolls determines the quantity of coating applied.

Coated workpieces are either air dryed or baked in ovens. Many processes employ a flashoff step at ambient temperatures in which solvent rises slowly to the surface of coated workpieces. This step prevents the formation of bubbles or blisters (orange peel effect) which can occur if solvent evaporates too quickly in baking ovens. Flashoff steps are sometimes done in tunnels, but the flashoff area is not always enclosed.

The quantity of emissions from surface coating operations depends on factors such as the type of material to be coated, coating thickness, desired finish, the application method, and coating formulation (percent water, solids, and solvent).[2] In most coating operations, 10 to 90 percent of the solvent is evaporated during the application and subsequent air drying (flash off) steps. The remaining 10 to 90 percent is evaporated in the drying oven. Table 7-2 shows how the emissions vary in application and drying steps depending on the application method. Table 7-3 describes emissions from wood and metal furniture coating operations.

TABLE 7-2. PERCENT OF TOTAL EMISSIONS FROM VARIOUS PROCESSES[2]

	Coating Process		
Coating Method	Application	Pre/Air Dry	Bake
Spray Coat	30-60	10-40	10-40
Dip Coat	5-10	10-30	50-70
Flow Coat	30-50	20-40	10-30
Roller Coat	0-10	10-20	60-90

TABLE 7-3. SOURCES OF ORGANIC EMISSIONS FROM INDUSTRIAL SURFACE COATING OPERATIONS[2,5]

Industry/Process	Percent of Total Emissions
WOOD FURNITURE COATING	
1) Spray booth	85
2) Oven	15
METAL FURNITURE COATING	
1) Electrostatic spray and flashoff	65
oven emissions	35
2) Conventional or airless spray	80
oven emissions	20
3) Dip applications	50
oven emissions	50
4) Flow application	60
oven emissions	40

Emissions from spray coating are produced when the sprayed material misses the surface to be coated (overspray).

The percentage of overspray as a function of spraying method and typical sprayed surfaces is given in Table 7-4. Solvent emissions from spray booth stacks can vary from less than 1.0 lb/day to more than 3,000 lb/day, depending on the extent of operation.[1]

TABLE 7-4. PERCENTAGE OF OVERSPRAY AS A FUNCTION OF SPRAYING METHOD AND SPRAYED SURFACE[2]

Method of Spraying	Flat Surface	Table Leg Surface	Bird Cage Surface
Air Atomization	50	50	90
Airless	20 to 50	90	90
Electrostatic			
Disc	5	5 to 10	5 to 10
Airless	20	30	30
Air Atomized	25	35	35

The quantity of solvent emissions also depends on the paint formulation. For example, emissions from application of a high solids coating (80% solids) are less than 2.0 lb of organic solvent per gallon of solids applied. Application of lacquer produces more than 4.5 lb of organic solvent per gallon of solids applied.

An equation for estimating the potential solvent emissions from surface coating operations is given below. It can be used to calculate emissions on the basis of coated area, thickness of coating, efficiency of application and solvent content.[2]

$$W = \frac{0.0623\ A\ n\ (1 - 0.01p)}{P\ f}\ \rho\ ,$$

where W = weight of solvent vapors in lb

A = area coated (sq ft)

n = thickness of dry coating (mils)

P = percent solids by volume

f = efficiency factor (dimensionless) empirically determined ($f \leq 1$), and

ρ = solvent density (lb/gal)

7.2 Levels and Sources of Emissions

The study area has an estimated 1,800 tons/year of hydrocarbon emissions from 40 surface coating operations. These emissions account for approximately 10 percent of the total emissions. The individual sources of surface coating emissions are listed by county in Table 7-5. Most of the surface coating operations in the study area are small operations, but five of the 40 sources have emission rates greater than 100 tons/year [company SC-1, company SC-4 (aircraft equipment), company SC-16 (metal furniture), company GS-1 (bread bags), and company SC-31 (small appliances)].

Hydrocarbon emissions in the study area are produced from coating wood products (16%, 292 tons/year), plastic and fiberglass products (21%, 389 tons/year) and metal products (46%, 825 tons/year). The remaining emissions of 300 tons/year (17% of total) are produced by area sources. Coating methods and products from industries classified as area sources are not defined, so control methods cannot be specified.

Table 7-6 describes emissions from wood coating in the study area. Some 292 tons/year of hydrocarbons are emitted from nine sources with a wide range of emission rates. Wood cabinets

TABLE 7-5. SUMMARY OF 1975 HYDROCARBON EMISSIONS FROM SURFACE COATING OPERATIONS IN THE STUDY AREA

Emission Sources	Description of Product or Operation	Method of Surface Coating	Hydrocarbon Emissions (tons/year)
Davidson County			
SC-1	Wood Cabinets	Spray Booths	140.0
SC-2	Wood cabinets	Spray Booths	59.9
SC-3	Wood Furniture	Spray Booths	62.0
SC-4	Aircraft Equipment	Spray Booths	139.8
SC-5	Industrial Handcarts	Spray Booth, Air Drying	39.2
SC-6	Large Truck Assembly	Spray Booth, Oven Drying	48.5
SC-7	Large Truck Trailers	Open Spraying, Air Drying	25.9
SC-8	Structural Steel Fabricating, Priming	Open Spraying, Air Drying	36.5
SC-9	Structural Steel Fabricating, Priming	Open Spraying, Air Drying	27.4
SC-10	Structural Steel Fabricating, Priming	Open Spraying, Air Drying	25.5
SC-11	Plastics, Toy	Spray Booth, Oven Drying	35.1
SC-12	Coated Wire Display Racks	Spray Booth, Oven Drying	15.2
SC-13	Large Truck Trailers	Spray Booth, Air Drying	6.2
SC-14	Wood Novelties	Varnish Dip Tank	15.6
Area Sources	Unknown (Various Types)	Unknown (Various Methods)	297.7
Rutherford County			
SC-15	Boat Building	2 Spray Booths	43.3
SC-16	Metal Furniture	22 Spray Booths Flow Coater	142.0 29.0
GS-1	Bag Manufacturer	Spray Booth Lamination (Roll) Strip Coater (Roll)	0.8 90.0 43.0
SC-17	Adhesive Application to Tape	1 Roll Coater	27.3
SC-18	Plastic Sign Manufacturer	12 Spray Booths, Oven Drying	53.7
SC-19	Fiberglass Shower Stalls	Spray Booths, Air Drying	81.3
SC-20	Wood Cabinets	Spray Booths	1.5
SC-21	Electric Housewares, Fans	Spray Booths	0.4
SC-22	Unknown	Spray Booths	0.2
SD-1	Decorations on Golf Balls, Ashtrays, and Cigarette Lighters	Spray Booths Spray Booths	0.7 2.5
SC-23	Wood Cabinets	Spray Booths	0.1
SC-24	Pumps	1 Spray Booth	0.6
SC-25	Wood Products	Spray Booths	0.4
SD-2	Unknown	Spray Booths	0.5
SC-26	Wood Cabinets	Spray Booths	9.2
Sumner County			
SC-27	Metal Office Furniture	Spray Booths, Oven Drying	32.7
SC-28	Unknown	Spray Booths	2.9
SC-29	Aluminum Extrusion, Outdoor Furniture	2 Spray Booths	17.6
SC-30	Boat Manufacturer	Spray Booths	0.1
Williamson County			
SC-31	Fans, Heaters and Can Openers	4 Spray Booths, Air Drying	153.6
SC-32	Electrical Components for Water Heaters	Spray Booths, Air Drying	8.9
Wilson County			
SD-3	Motor Vehicle Parts	3 Spray Booths	57.3
SC-33	Clocks and Time Controls	6 Spray Booths	35.7
SC-20	Wood Cabinets	Spray Booths	1.5
SC-35	Wood Cabinets	Spray Booths	1.4
SC-36	Casket Manufacturer	2 Spray Booths	14.7
SC-37	Appliance Racks	Open Spraying, Oven Drying	0.3

TABLE 7-6. SUMMARY OF HYDROCARBON EMISSIONS FROM SURFACE COATING OF WOOD PRODUCTS IN THE STUDY AREA

Emission Source	Description of Facility and Products		Hydrocarbon Emissions (tons/yr)	
SC-1	Manufactures wood cabinets. Surface coating materials are applied in a spray booth. Emissions are estimated from coating material losses (48,000 gal/yr, 7.71 lb coating/gal, 0.793 lb solvent/lb coating). No control methods are in use.		Solvent emissions from spraying	140
SC-2	Manufactures wood cabinets. Coatings applied in spray booths.		Solvent emissions from spraying	60
SC-3	Manufactures wood furniture. Five emission points are identified:			
	3 prefinishing steps	23 tons/yr	Solvents from prefinishing	23
	Spray booth	4 tons/yr	Spraying emissions	4
	Drying oven	35 tons/yr	Drying oven emissions	35
SC-14	Produces yardsticks and other wood novelties. Varnish applied in a dip tank.		Dip tank and drying emissions	15.6
SC-26	Manufactures wood cabinets. Enamel and lacquer applied in spray booth operating 500 hrs/yr. No controls in use.		Spraying emissions	9.2
SC-20	Manufactures wood cabinets. Coatings applied in spray booth.		Spraying emissions	1.5
SC-23	Manufactures wood cabinets. Coatings applied in a spray booth.		Spraying emissions	0.1
SC-25	Manufactures wood products. Polyurethane coatings are applied in a spray booth.		Spraying emissions	0.4
SC-35	Manufactures wood cabinets. Coatings applied in a spray booth		Spraying emissions	1.4

are manufactured in six of the operations, and one location makes furniture. Coatings are applied in spray booths at all but one facility. It is not known whether air drying or oven drying is used in most of these operations. In order to define sources of hydrocarbon emissions for purposes of specifying control methods, it was assumed that 80 percent of the emissions are produced in the application step (spraying and flash off) and 20 percent in the drying step (see Table 7-3).

Table 7-7 gives available information about the plastic and fiberglass coating operations in the study area. These sources produce 389 tons/year of hydrocarbon emissions at seven locations. Both spraying and roll coating are used. Not all of the emissions are produced by surface coating; 90 tons/year are solvent emissions from polyetheylene laminating. Control methods were not considered for laminating process emissions. In estimating the volume of emissions from spraying and drying, it was assumed that 60 percent are produced in the application step and 40% in the drying step (see Table 7-2).

There are nineteen metal coating operations in the study area. The facilities and emission sources are described in Table 7-8, which shows the diversity of operations. Three facilities produce metal furniture; three fabricate structural steel; two make truck trailers; two coat wire racks; two make metal parts for airplanes or cars; six manufacture small appliances, equipment, or components; and one assembles large trucks. All of the operations use spraying as the application method, and some open spraying is employed. Both air drying and oven drying are used.

The information in Tables 7-6, 7-7, and 7-8 was used to estimate the volume of hydrocarbon emissions from application

TABLE 7-7. SUMMARY OF HYDROCARBON EMISSIONS FROM SURFACE COATING OF PLASTIC PRODUCTS IN THE STUDY AREA

Emission Source	Product	Facility Description	Sources and Hydrocarbon Emissions (tons/year)	
CS-1	Polyethylene bread bags	Polyethylene pellets are processed in a roll laminator and coating is applied in a roller operation. Shellac is applied in a spray booth.	Spray booth emissions Laminator solvent emissions Roller coating emissions	0.8 90 43
SC-11	Plastic toys	Epoxy paint is applied in 10 spray booths. Painted articles are oven dried. Total paint consumption (1977) 8175 gal/yr. Solvent consumption (1977) 2500 gal/yr MEK, 10,000 gal/yr acetone, 1960 gal/yr thinner. Solvent losses not included in emissions.	Spray booth emissions Drying oven emissions	21 14
SC-18	Plastic signs	Paint of various colors is applied in 12 spray booths with oven drying.	Spray booth emissions Drying oven emissions	32 22
SC-17	Tape	Adhesive is applied to tape in a roll coater.	Roller coating emissions	27
SC-36	Caskets	-	Spray booth emissions Drying emissions	9 6
SC-19	Fiberglass shower stalls	Coatings applied in spray booths with air drying.	Spray booth emissions Air drying emissions	49 32
SC-15	Fiberglass boats	-	Spray booth emissions Drying emissions	26 17

TABLE 7-8. SUMMARY OF HYDROCARBON EMISSIONS FROM SURFACE COATING OF METAL PRODUCTS IN THE STUDY AREA

Emission Source	Product	Facility Description	Sources and Hydrocarbon Emissions[a] (tons/yr)	
SC-4	Metal airplane parts	There are nine emission points: 1. 6 spray booths 14 tons/yr 2. 4 spray booths 18 tons/yr 3. several spray booths 16 tons/yr 4. 1 spray booth 4 tons/yr 5. 1 spray booth 7 tons/yr 6. 6 spray booths 23 tons/yr 7. 9 spray booths 53 tons/yr 8. 6 spray booths 0.5 tons/yr 9. Degreasing aluminum parts 5 tons/yr No controls are in use at spray booths. Drying method was not described in available information.	Spray booth emissions Drying emissions Degreasing emissions	81 54 5
SC-5	Industrial hand carts	Cart frames are spray painted in booths and air dried.	Spray booth emissions Air drying emissions	23 16
SC-6	Large truck assembly	Coatings applied in spray booths and dried in ovens.	Spray booth emissions Drying oven emissions	29 19
SC-13	Truck beds and trailers (dump trucks, cattle trailers) for existing truck chasis	Consumes 1800 gal/yr enamel and 3000 gal/yr primer. Coatings applied in a spray booth with air drying.	Spray booth emissions Air drying emissions	4 2
SC-7	(same as Rogers Manufacturing)	Coatings applied by open spraying with air drying. Emissions consist of: primer 2 ton/yr varnish 10 ton/yr paint 14 ton/yr	Open spraying, air drying	26
SC-8 SC-9 SC-10	Structural steel fabrication	Prime coating is applied by open spraying. Coated steel is air dried. Total emissions 89.4 tons/yr	Open spraying emissions Air drying emissions	53 36
SC-12	Coated wire display racks	A conveyor system is employed. Wire racks are coated in two spray booths and a dip tank. A drying oven is used. 1977 emissions were 21 tons/yr (15 tons/yr in 1975)	Spray booth emissions Dipping, air drying Oven emissions	5 4 6
SC-37	Appliance racks	Open spraying and air drying	Spraying and drying	0.3
SC-27	Metal office furniture	Coatings are applied in spray booths and dried in ovens	Spray booth emissions Drying oven emissions	26 7
SC-29	Extruded aluminum outdoor furniture	Acrylic coatings are applied in 2 spray booths, air drying is employed.	Spray booth emissions Air drying emissions	11 7
SC-16	Metal furniture		Spray booth emissions Drying emissions Flow coating emissions Drying emissions	85 57 17 12
SC-31	Fans, heaters, can openers	Appliances are coated in 4 spray booths and air dried.	Spray booth emissions Air drying emissions	92 61
SD-3	Motor vehicle parts	Metal parts are coated in 3 spray booths.	Spray booth emissions Drying emissions	34 23
SC-33	Clocks, time controls	Products are coated in 6 spray booths.	Spray booth emissions Drying emissions	21 15
SC-32	Electrical components for water heaters	Components are coated in spray booths and air dried.	Spray booth emissions Drying emissions	5 4
SC-24	Pumps	-	Spray booth emissions	0.6
SC-21	Electric fans, housewares	-	Spray booth emissions	0.4

[a] estimated from emissions factors in Tables 7-2 and 7-3 depending on coating and drying methods

and drying steps in the surface coating operations in the study area. Table 7-9 summarizes the results. It shows that emissions from spray booths are 731 tons/year and drying oven emissions are 145 tons/year. Open spraying produces 79 tons/year and 342 tons/year are produced by air drying or undefined drying methods.

7.3 Control Technology

Hydrocarbon emissions from surface coating operations can be reduced by process and material changes and by add-on control devices. Each surface coating industry is presented with unique emission problems since the industries differ in raw materials, coatings and products. Solutions to these problems will vary by industry and for each facility.

Process and material changes include electrostatic spray coating, electron beam curing, ultraviolet curing, and coating modifications such as waterborne coatings, high solids coatings, powder coatings, and hot melt formulations.[2] Table 7-10 gives available information about control efficiencies of process and material changes for some industries.

Add-on control devices include carbon adsorption units and incinerators.[3] Table 7-11 summarizes the utility and efficiency of add-on controls for some surface coating operations. Incineration is generally applied to drying oven exhaust, and carbon adsorption is generally used to control emissions from the application and flashoff steps.

EPA has published guidelines about emission limitations and control methods for the surface coating operations listed in Tables 7-10 and 7-11. But there are many other industrial surface coating operations for which EPA guidelines are unavailable.[4]

TABLE 7-9. SOURCES OF HYDROCARBON EMISSIONS IN SURFACE COATING OPERATIONS IN THE STUDY AREA

Coated Substrate	Emission Source	Emission Rate (tons/year)
Wood Cabinets and Furniture[a] (see Table 7-6)	Prefinishing	23
	Spray booth	175
	Drying oven	77
	Dipping and Drying	16
	TOTAL (Wood)	291
Plastic Products (see Table 7-7)	Spray booth	138
	Roller coating and drying	70
	Drying oven	36
	Air drying or undefined drying method	55
	Laminating	90
	TOTAL (Plastic)	389
Metal Products (see Table 7-8)	Spray booth	418
	Open spraying	79
	Drying oven	32
	Air drying or undefined drying method	287
	Dipping and Drying	4
	Degreasing	5
	TOTAL (Metal)	825
Undefined (area sources)	Undefined	300
	TOTAL EMISSIONS	1805

[a] emissions estimated assuming that drying ovens are used and 20% of the emissions are produced in the drying step

TABLE 7-10. EFFICIENCIES OF PROCESS & MATERIAL CHANGES AS CONTROL METHODS FOR HYDROCARBON EMISSIONS FROM SURFACE COATING APPLICATIONS[2,5]

	Control Efficiency						
	Waterborne Coatings	High-Solids Coatings	Powder Coatings	Hot Melt Formulations	Ultraviolet Curing	Plastisols	Extrusion Coatings
Metal Coating							
Auto & Light Truck Assembly	80-93[a] 40-92[b]	70-90	-	-	-	-	-
Can Coating	70-95	70-95	100	-	100	-	-
Coil Coating	70-95	70-90	-		-	-	-
Large Appliance Coating	80 99 [a]	57	99	-	-	-	-
Fabric Coating	80-100	80-100	-	100	-	-	-
Paper, Film, & Foil Coating	80-99	-	-	100	-	95-99	99+
Adhesives Coating	80-99	-	-	80-99	80-99	-	-
Flat Wood Products Coating	80	-	-	-	100	-	-
Metal Furniture	90-95[a] 60-90[b]	50-80	95-99	-	-	-	-

[a] Electrodeposition of primer

[b] Topcoat

TABLE 7-11. TYPICAL EFFICIENCIES FOR ADD-ON CONTROL EQUIPMENT[2,5]

Industry	Control Efficiency (Percent) Carbon Adsorption	Control Efficiency (Percent) Incineration Thermal/Catalytic
Metal Coating		
Auto & Light Truck Assembly	85+	95/95
Can Coating	85-90	90-98/90
Coil Coating	a	90-98/90
Large Appliance Coating	a	81
Magnet Wire Coating	a	90-95/90-95
Metal Furniture	90[b]	90[b]
Fabric Coating	90-95	90-95/90-95
Paper, Film, & Foil Coating	90+	95/95
Flat Wood Products Coating	a	90

[a] Not used in this industry

[b] Doesn't include capture efficiency

Most of the operations in the study area are in the group of industries for which control methods and specific guidelines have not been suggested by EPA.

EPA has stated as a general guideline for such industrial surface coating operations that "low solvent coatings, i.e. powder, water-borne, and high solids coatings . . . are adaptable to many metal and plastic products. Low solvent coating may represent the most cost-effective means of control when the coating is hand sprayed or air dried."[4] Industries included in this category are transportation equipment, marine equipment, factory finished building products, and fabricated metal and plastic products in general. Low-solvent coating methods and their applicability for coating metal and plastic products are summarized in Table 7-12.

A limited amount of information is available concerning control of solvent emissions during fiberglass product manufacturing.[6] A program for reducing emissions was employed at a boat hull manufacturing company where styrene emissions were 14 percent of total consumption. Styrene losses occur during resin spray application in the gel coat step and from spray gun cleanup. Several control methods were considered. Carbon adsorption and incineration were not considered feasible because of the low volume of hydrocarbon emissions. Airless spraying was considered. The properties of the finish were not suitable for boat hulls but were said to be acceptable for other products such as shower stalls. The control method employed was a new "suppressed" resin which prevents styrene emissions during the gel coat step. The resin dries by catalytic polymerization (resin crosslinking). Solvent emissions (acetone, MEK) were also minimized by improved housekeeping practices in the spray gun cleanup operation and by recycling spent solvent instead of dumping it.

Control methods for wood product surface coating have not been formally addressed by EPA in specific guideline documents. But some information is available about the applicability of water-borne coatings. Conventional wood coatings contain 12 to 20% solids. They consist of nitrocellulose resins in about 80% organic solvent. Water-based coatings contain 25-30% solids, 10-20% solvent, and about 50% water. They employ polyvinyl acetate or acrylic resin emulsions. Some contain amino resins which act as crosslinking agents at drying temperatures of 140°F.

TABLE 7-12. LOW-SOLVENT COATING METHODS APPLICABLE TO SURFACE COATING OPERATIONS IN THE STUDY AREA[4]

Coated Product	Control Method	Applicability	Control Efficiency (%)
Metal and plastic products	Substitution of high solids (33%) coatings (conventional coatings average 20% solids)	Commercially available and in use in many products. Employs conventional application methods and equipment.	50
Small metal products coated in only a few colors (metal furniture, small metal parts, fabricated metal products)	Prime coat: electrostatic spraying Top coat: powder coating	Used by numerous sources in both new and retrofit installations. Superior finish is obtained. Not applicable for heat sensitive products or for operations with frequent color change.	Approaches 100
Small metal products coated by dipping or spraying	Water-borne coatings	-	80-90

Water-based coatings are being developed by coating suppliers for use in the wood furniture industry, but commercial use is still limited to flat wood products such as wood paneling. Table 7-13 summarizes information from trade journals describing new water-based coating materials.

Furniture manufacturers are working with suppliers to demonstrate new water-based coating technology and reduce it to practice. Coating suppliers have predicted a transition from conventional solvent-borne coatings to water-based coatings by 1980. There are problems to be solved before acceptance by manufacturers will occur. Water-borne coatings are more difficult to apply than solvent-borne coatings, and drying times are longer. This results in reduced coating line speeds and lower production rates. Application is difficult in humid weather, and some coatings are not resistant to water and alcohol stains.

There are no published data on the efficiency of reduction of hydrocarbon emissions associated with the use of water-borne coatings for wood products. Water-borne coatings contain about 75 percent less solvent than conventional coatings. In calculating possible reductions in hydrocarbon emissions from substitution of water-based coatings, a 75 percent reduction efficiency was assumed.

It is not feasible to suggest specific control methods for each surface coating operation in the study area because of the diversity of products and coatings. Information about the specific emission sources is too limited to allow very accurate general predictions about the applicability of control methods. Potential control methods include add-on devices (carbon adsorption for spray booth emissions and incineration for drying oven emissions) and process changes (substitution of low solvent or water-based coatings).

TABLE 7-13. WATER-BASED COATING MATERIALS FOR WOOD PRODUCTS DESCRIBED IN TRADE JOURNALS

Coating Material and Application Method	Coated Product	Advantages	Reference
Water-borne varnish applied in single dip coat to work pieces suspended on conveyor hooks. Materials can be handled after 20 minutes of air drying	Oak, birch, maple and hickory hard woods	Reduction in plant heating costs because ventilation with outside air is not required. 30% increase in coverage gives decreased coating consumption. Reduced insurance rates	Industrial Finishing, March 1976, pp. 16-17
Stains and lacquers (Acrylate emulsion containing small amount of solvent)	Light and dark wood surfaces	Reduced requirements for plant ventilation, shorter drying times than conventional lacquers. Reduced blistering during rapid drying	Pigment and Resin Technology, March 1976, p. 20
Water-based stain, sealer, glaze, and clear top coat	-	-	Furniture Design and Manufacturing, April 1976, p.14
Water-based coating for flow application	Hardboard, particle board, paneling	-	Furniture Design and Manufacturing, April 1976, p.14
Clear top-coat applied by spraying which dries by polymerization	-	-	Furniture Design and Manufacturing, April 1976, p.14
Water-based stain applied in dip tank	Chairs	-	Furniture Design and Manufacturing, April 1976, p.14
Electrostatic spray coating used on wooden parts in conveyor (monorail transport) coating line. Conductive surface coating applied first by dip or spray	-	Eliminates coating losses due to overspray	Furniture Design and Manufacturing, April 1976, p.14

Table 7-14 shows the reduction in hydrocarbon emissions that would be obtained with the application of add-on control technology and process change. The application of these control methods is hypothetical and there is limited factual basis for assuming the control methods would be useful in these applications. The feasibility of application of add-on devices depends in part on the hydrocarbon concentration, exhaust gas rate, quantity of emissions, and existing equipment configurations. Such information is unknown for the emission sources in the study area. The key factor governing applicability of substitute coatings is whether the product meets normal use specifications when coated with the substitute coating.

Table 7-14 shows that 49% of the hydrocarbon emissions from surface coating (spray booth and drying oven emissions) might be treated with add-on control devices for an overall reduction of 42% of the total emissions. About 75% of the emissions might be controlled by process change or substitute coatings for an overall reduction of 65% of the total emissions. Again, there is limited basis for judging whether the control methods are really applicable to specific emission sources, so the potential reductions shown in Table 7-14 are hypothetical.

7.4 Capital and Operating Cost

The costs of process or material changes are difficult to quantify. The costs will vary from plant to plant, depending on the types of processes and equipment in use. Also, secondary costs may result from the necessity to test the application and performance of new coatings and from equipment alterations.[3,4]

Generalized cost data have been determined for add-on control devices for surface coating.[3] The cost figures for direct flame and catalytic incinerators with no heat recovery,

TABLE 7-14. REDUCTION IN HYDROCARBON EMISSIONS FROM SURFACE COATING OPERATIONS IN THE STUDY AREA FROM APPLICATION OF ADD-ON CONTROL DEVICES AND PROCESS CHANGE

Description of Emissions	Hydrocarbon Emissions (tons/year)	Control Method	Reduction Efficiency (%)	Hydrocarbon Emissions Remaining After Controls (tons/year)
Spray booth emissions from coating wood, metal, and plastic products	731	Carbon adsorption	85	110
Drying oven emissions from coating wood, metal, and plastic products	145	Incineration	90	15
Remaining emissions for which add-on control devices are not applicable	924	None specified	-	924
TOTAL	1800			1049
Total emissions from wood product coating	291	Substitution of water-borne coatings	75	73
Emissions from metal product coating	820	Substitution of electrostatic spraying, powder coatings	99	8
Emissions from plastic product coating	299	Substitution of low solvent, high solids coatings	50	150
Emissions from unidentified area services, degreasing, and roll laminator	390	None specified	-	390
TOTAL	1800			621

primary heat recovery, and primary and secondary heat recovery at minimum retrofit were calculated. Direct flame incinerators with primary heat recovery were found to be most cost effective. The assumptions used in calculating costs are provided in Table 7-15.

Cost figures were estimated at three concentration levels (∿100 ppm, 15 percent LEL, and 25 percent LEL), at three inlet exhaust gas flow rates (5,000, 15,000, and 30,000 scfm) and at two inlet stream temperatures (70 and 300°F). Capital costs, net annualized costs, and cost effectiveness for each case are given in Table 7-16.

7.5 Economic Impact of Control Cost

The economic impact of control costs for surface coating operations has not been defined. The cost of process and material changes could range from negligible to a large expenditure of money and time. Another difficulty in defining economic impact is the variation in financial stability of the different industries which employ surface coating operations. Some industries have better access to capital than others.

7.6 References

1. Danielson, John A., Air Pollution Engineering Manual. PHS Publication No. 999-AP-40. National Center for Air Pollution Control, 1967.

2. Radian Corporation, Control Techniques for Volatile Organic Emissions from Stationary Sources, DCN 200-187-12-07, EPA Contract No. 68-02-2608, Task 12, Austin, Texas, September, 1977.

TABLE 7-15. ASSUMPTIONS USED IN DEVELOPING COST ESTIMATES FOR NONCATALYTIC INCINERATORS[3]

- Noncatalytic incinerators designed for both oil and natural gas operation.
- Exhaust gases contain benzene and hexane (50/50 molar percent) mixture in air.
- Costs based on outdoor location.
- Rooftop installation requiring structural steel.
- Fuel cost of \$1.50 million Btu (gross).
- Electricity at \$0.03 kwhr.
- Depreciation and interest was taken as 16 percent of capital investment. Annual maintenance was assumed to be 5 percent of capital cost, taxes and insurance, 2 percent, and building overhead, 2 percent.
- Direct labor assessed at 0.5 hr/shift x 730 shifts/yr x \$8.00/hr = \$2920/yr direct labor expense.
- Operating time: 2 shifts/day x 8 hr/shift x 365 days/yr = 5840 hr/yr.
- The noncatalytic incinerator utilized was based on:
  - 1500°F capability.
  - 0.5-second residence time.
  - Nozzle mix burner capable of No. 2 thru No. 6 oil firing.
  - Forced mixing of the burner products of combustion using a slotted cylinder mixing arrangement. This cylinder allows the burner flame to establish itself before radial entry of the effluent thru slots in the far end of the cylinder.
  - A portion of the effluent to be incinerated is ducted to the burner to serve as combustion air. This allows the burner to act as a raw gas burner, thus saving fuel over conventional nozzle mix burners. This design can only be used, however, when the O_2 content of the oven exhaust is 17 percent by volume or above.

TABLE 7-16. CAPITAL COST, ANNUAL COST, AND COST EFFECTIVENESS OF DIRECT FLAME INCINERATION WITH PRIMARY HEAT RECOVERY FOR CONTROL OF HYDROCARBON EMISSIONS FROM SURFACE COATING OPERATIONS[3]

Inlet Stream Temperature (°F)	70			300		
Stream Concentration	100 ppm	15% LEL	25% LEL	100 ppm	15% LEL	25% LEL
Inlet Flow Rate - 5,000 scfm						
Capital Cost ($000)	126.0	126.0	126.0	126.0	126.0	126.0
Annual Cost ($000)[a]	84.0	52.5	36.8	78.8	52.5	36.8
Uncontrolled Emissions (tons/yr)	20.0	390.0	650.0	20.0	390.0	650.0
control efficiency (%)	88	77	77	88	77	77
Cost Effectiveness ($000/ton)	4.8	0.18	0.07	4.4	0.18	0.07
Inlet Flow Rate - 15,000 scfm						
Capital Cost ($000)	157.5	157.5	157.5	157.5	157.5	157.5
Annual Cost ($000)[a]	194.3	115.5	57.8	173.3	94.5	42.0
Uncontrolled Emissions (tons/yr)	66.0	1170.0	1950.0	60.0	1170.0	1950.0
control efficiency (%)	92	81	82	92	81	82
Cost Effectiveness ($000/ton)	3.5	0.12	0.04	3.2	0.10	0.03
Inlet Flow Rate - 30,000 scfm						
Capital Cost ($000)	204.8	204.8	204.8	204.8	204.8	204.8
Annual Cost ($000)[a]	367.5	210.0	105.0	320.3	157.5	73.5
Uncontrolled Emissions (tons/yr)	120.0	2340.0	3900.0	120.0	2340.0	3900.0
control efficiency (%)	96	86	85	96	86	85
Cost Effectiveness ($000/ton)	3.3	0.11	0.03	2.8	0.08	0.02

[a] Includes capital charges, operating costs, overhead, and maintenance costs in accordance with assumptions given in Table 7-15.

3. Environmental Protection Agency, Emission Standards and Engineering Division, Chemical and Petroleum Branch, Control of Volatile Organic Emissions from Existing Stationary Sources, Vol. 1, Control Methods for Surface-Coating Operations. EPA 450/2-76-028, OAQPS No. 1.2-067, Research Triangle Park, North Carolina, November, 1976.

4. Environmental Protection Agency, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. Research Triangle Park, North Carolina, May, 1977.

5. Environmental Protection Agency, Office of Air Quality and Standards, Control of Volatile Organic Emissions from Existing Stationary Sources, Volume III Surface Coating of Metal Furniture. EPA 450/2-77-032, Research Triangle Park, North Carolina, December, 1977. (OAQPS No. 1.2-086)

6. Personal Communication, S. Growther, Texas State Air Control Board, March 17, 1978.

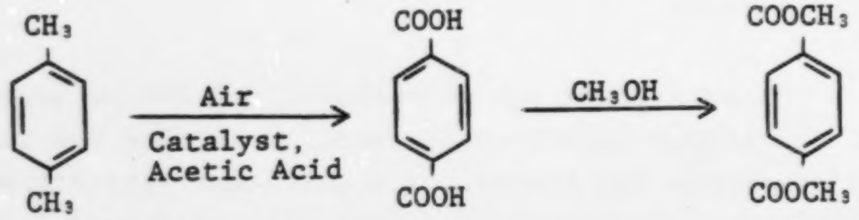
8.0 HYDROCARBON EMISSIONS FROM ORGANIC CHEMICAL PRODUCTION

The Nashville area has only one known source of chemical plant emissions, company OC-1's dimethyl terephthalate (DMT) plant in Davidson County. This facility currently emits an estimated total of 4400 tons/year of hydrocarbons (process emissions plus fugitive emissions). The values for OC-1's plant emissions were obtained from files of the Davidson County Health Department. The data reported by OC-1 include only process emissions. No data were reported for fugitive emissions.

A company OC-1 report on possible control schemes and their costs was supplied by the Davidson County Health Department.

8.1 Description of Operations, Emission Sources and Emission Rates

All of the dimethyl terephthalate (DMT) and terephthalic acid (TPA) produced in the United States is based on p-xylene feedstock[1]. Para-xylene is oxidized at moderate temperature and pressure in acetic acid solvent using heavy metal catalyst. The crude TPA product is esterified with methanol to give DMT. The chemistry of the process is shown below.



p-xylene TPA DMT

Commercial TPA is produced by a process based upon a bromine promoted heavy metal catalyst, such as cobalt-manganese. The process operates at 177-233°C (350-450°F) and 137.9 x 10^4 pascals (200-400 psig). The preheated acetic acid, activated catalyst, and p-xylene are charged to a reactor with high-pressure air. The products are continuously discharged from the bottom of the reactor. In the crystallizer, part of the acetic acid, unreacted xylene and water of reaction are flashed off. The TPA is sent to a centrifuge for removal of the remaining acetic acid and xylene. The filter cake is then washed. The spent liquor and condensate from the crystallizer are distilled to remove water, recover unreacted xylene and acetic acid, and remove any other by-products. The acetic acid is recycled. Esterification of the TPA with methanol produces DMT.[2]

The liquid phase oxidation reactor is normally a packed or plate tower in which air flows upward through the liquid reaction mixture. Emissions from this system consist of hydrocarbons carried by the nitrogen (from air) which must be vented. In OC-1's plant, the HP absorber which operates at 315 psia and 120°C probably produces this vent stream.

The TPA is crystallized and pneumatically conveyed by absorber vent gas. This stream contains some hydrocarbons and is at low pressure.

The esterification of methanol and TPA to form DMT is a relatively simple liquid-solid reaction carried out in a mixing tank and generates few inerts. A significant vent stream would not be required. Some methyl acetate will be formed from acetic acid carried in by the TPA crystals and this material is either hydrolyzed or vented. Some methyl acetalate is eventually vented.

Other operations necessarily involved are removal of the water formed in the oxidation of the p-xylene to TPA, distillation of the unreacted paraxylene to remove ortho-xylene, and removal of high boiling compounds from the acetic acid recycle stream. Vents would be required for these operations but they are not identified in data supplied by OC-1.

Table 8-1 presents company OC-1's emission data by emission source. The major sources are described as follows.[3]

Emission Source G-2 Silo Bag Filter Vent

This stream is primarily gas used to pneumatically convey TPA from the drier to the storage silos. The conveying gas is part of the high pressure absorber offgas and therefore has the same impurities as that stream. Particulates picked up in the conveyor are removed by a bag filter prior to venting.

Emission Source G-4 H.P. Absorber Offgas

The absorber operates at a high efficiency in removing water soluble components (primarily acetic acid). However, only a small part of the other major hydrocarbon, methyl acetate, is removed by this device because of its high vapor pressure and relative insolubility in water. The absorber is about 70% efficient in hydrocarbon removal.

The emissions in Table 8-1 total 3400 tons/yr and consist entirely of process emissions. In the chemical industry in general, it has been estimated that process emissions are about 60% of total emissions and fugitive emissions account for 40% of the total.[4] Total emissions are about 1.23% of plant throughput (0.7% process emissions, 0.5% fugitive). Stringent

TABLE 8-1. PROCESS EMISSIONS FROM DMT AND TPA MANUFACTURE REPORTED BY COMPANY OC-1

Operation	Emission Point Designation	Description	Organic Vapor or Hydrocarbon Emissions (tons/year)	Composition
Terephthalic Acid Manufacture	G-1	Absorber (90% efficient)	11.8	Acetic Acid
Terephthalic Acid Manufacture	G-2	Silo Bag Filter Vent	189.5	Acetic Acid
Terephthalic Acid Manufacture	G-4	Absorber (70% effluent, removes acetic acid and some methyl acetate)	2,400.0	80% Methanol 20% Xylene
			280.0	Acetic Acid Methylacetate
Terephthalic Acid Manufacture	G-21 G-22	Water Scrubber Pneumatic System Star Values	11.2	Benzoic Acid
Dimethyl Terephthalate Manufacture	G-5	Condenser (90% efficient)	57.0	Methanol
Dimethyl Terephthalate Manufacture	G-6	Sludge Bottom Scrubber Vent	16.5	O-Xylene
Dimethyl Terephthalate Manufacture	G-7	Condenser (90% efficient)	52.5	Methanol
Dimethyl Terephthalate Manufacture	G-8	Condenser (90% efficient)	20.5	Methanol
Purification of Crude Dimethyl Terephthalate	G-9	Condenser (88% efficient)	114.0	O-Xylene
Purification of Crude Dimethyl Terephthalate	G-10	MPT Column Condenser (81% efficient)	10.0	O-Xylene
Purification of Crude Dimethyl Terephthalate	G-11	Crude DMT Tank Scrubber	16.5	O-Xylene
Purification of Crude Dimethyl Terephthalate	G-19	Condenser (88% efficient)	57.0	Xylene
Purification of Crude Dimethyl Terephthalate	G-20	Condenser (88% efficient)	57.0	Xylene
Product Storage	G-12	Final Product Tank Scrubber	69.9	Methanol
Acetic Acid Storage	G-14	Acetic Acid Tank Scrubber (90% efficient)	3.5	Acetic Acid
Methanol Storage	F-4 F-5	Weak and Working Methanol Storage Tank Vents	12.0*	Methanol
Methanol Storage	F-8	Dacron Recovery Methanol Tank	8.0*	Methanol
Reemay Manufacture	R-30	Unknown	4.1	Unknown
Reemay Manufacture	R-31	Unknown	8.1	Unknown
Reemay Manufacture	R-32	Unknown	7.1	Unknown
Shipping	T-27 T-28 T-29 T-30	Glue Package Labels	4.8	Unknown Solvent

*Estimated from emission rate (8,000 hrs) shown in "Summary of Cost and Energy Consumption for VOC Abatement". Emission rate for F-4 + F-5 is 3 lb/hr, for F-8 emission rate is 2 lb/hr.

control practices, however, can maintain fugitive emissions at 0.2% of throughput. Based on 0.7% of throughput as process losses, 0.2% as fugitive loss, and 3,400 tons/yr for process losses, fugitive emissions were calculated to be about 1,000 tons/yr. This means total fugitive and process emissions would be about 4,400 tons/yr.

8.2 Control Methods, Costs, and Cost-Effectiveness

Company OC-1 evaluated control methods for achieving 90% removal efficiency at the Nashville Plant.[3] The control method selected by OC-1 for each emission source is listed in Table 8-2. Control costs estimated by OC-1 are listed in Table 8-3.

Company OC-1 has specified control methods for process streams emitting a total of about 3,000 tons/yr.[3] Total process emissions were reported at about 3,400 tons/yr. Thus, about 88 percent of process emissions can be treated using the specified control technology. Assuming 90% control efficiency, these emissions could be reduced by 2,700 tons/yr to 300 tons/yr. The sum of the annual operating costs listed in Table 8-3 in 1980 dollars is $2.2 million/year ($1.8 million/year in 1977 dollars). Therefore, the cost effectiveness of the control methods specified by OC-1 for DMT manufacture is $800/ton controlled ($670/ton in 1977 dollars). The estimated capital cost of controls in 1980 dollars obtained by adding the capital costs in Table 8-3 is $3.9 million ($3.2 million in 1977 dollars). The accuracy of these estimates is around ±40%.

8.3 Economic Impact of Control Methods

The energy requirement for 90% control was estimated to be about 5×10^{11} Btu/yr, which represents a 10% increase in the amount of energy required for DMT production. The operating

TABLE 8-2. METHODS SELECTED BY COMPANY OC-1 FOR CONTROL OF PROCESS EMISSIONS FROM DMT PLANT

Emission Point Description	Control Method Specified By Company OC-1	Comments
G-2 Silo bag filter vent	Thermal incineration (1800^oF) with heat recovery (63% efficient heat exchanger)	This stream could be combined with stream G-4 (high pressure absorber off-gas). Energy required for supplemental fuel is 14×10^9 Btu/yr.
G-4 High pressure absorber off-gas	Thermal incineration (1800^oF) with heat recovery (63% efficient heat exchanger)	Energy required for supplemental fuel is 496×10^9 Btu/yr. Equipment must be at a remote location and constructed of stainless steel. Waste heat cannot be used for steam generation because steam needs are already supplied by waste heat boilers.
G-6 Sludge bottom tank scrubber vent	Fuel oil scrubber	Fuel value could be recovered by combustion of fuel in existing units.
G-10 MPT jet condenser vent	Eliminate by process change	Bypass to xylene jet condensers.
G-11 Crude DMT tank scrubber	Fuel oil scrubber	
G-12 Final product tank scrubber	Water scrubber	Water-methanol mixture can be recycled for methanol recovery. An increased load to plant water treatment facility would result.
G-21, G-22 Pneumatic system star valves	Process change could eliminate these sources	

TABLE 8-2. METHODS SELECTED BY COMPANY OC-1 FOR CONTROL OF PROCESS EMISSIONS FROM DMT PLANT (Continued)

Emission Point Description	Control Method Specified By Company OC-1	Comments
F-4,5,8 Methanol storage tanks	Water scrubbers	Water-methanol mixture can be recycled. An increased load to plant water treatment facility would result.
T-27,28,29,30 Gluing product labels	Process change	

TABLE 8-3. CAPITAL AND ANNUAL COST OF CONTROL METHODS FOR PROCESS EMISSIONS FROM DMT MANUFACTURE

Emission Source	Hydrocarbon Emission Rate Tons/Yr	Control Method	Capital Cost[1] (\$1000)	Net Annual Operating Cost[2] (\$1000/Yr)	Value of Material Recovered (\$1000/Yr)	Energy Consumption Credit (10^9 Btu/Yr)
G-2 Silo bag filter vent	189.5	Incineration	750	170	0	13.6
G-4 Absorber vent	2,680.	Incineration	3000	2018	0	496
G-6 Sludge bottom tank scrubber vent	16.5	Fuel oil scrubber	25	1.8	1.4	(5.)
G-11 Crude DMT tank scrubber	16.5	Fuel oil scrubber	25	2.7	1.4	(5.)
G-12 Final product tank scrubber	69.9	Water scrubber	35	0.5	7.4	0.3
F-4, 5 Methanol storage tank	Not Reported	Water scrubber	15	1.5	1.4	0.06
F-8 Dacron recovery methanol storage tank	Not Reported	Water scrubber	15	1.5	0.9	0.06
T-27,28,29,30 Gluing product labels	4.8	Process change	40	No change	0.	0.

[1] Capital costs in 1980 dollars based on cost of construction index (CCI) of 261. Additional capital cost (not shown) 10% of capital investment for engineering liaison and startup.

[2] Net operating cost includes depreciation, maintenance, wages and salaries, power and fuel cost. Value of energy and material recovered is taken as credit No. 2 fuel oil credited at \$3/10^6 Btu. Operating costs in 1980 dollars.

costs of about $2 million/yr were reported by company OC-1 "large fraction" of the profit margin for DMT production.[3]

8.4 References

1. Chemical Economics Handbook. Stanford Research Institute, Menlo Park, CA., various dates.

2. Industrial Process Profiles for Environmental Use, Ch. No. 6(f), Industrial Organical Chemicals, EPA 600/2-77-023f, EPA Contract No. 68-02-1319, Task 34. Austin, TX., Radian Corporation, various dates.

3. Letter from Thomas C. Fisher (company OC-1) to Paul Bontrager (Metropolitan Health Department) dated 15 June 1977.

4. Radian Corporation, Hydrocarbon Pollutants from Stationary Sources, EPA 600/7-77-110, EPA Contract No. 68-02-1319, Task 48, Austin, TX., September 1977 (Page 147).

9.0 HYDROCARBON EMISSIONS FROM RUBBER PROCESSING (TIRE MANUFACTURING)

9.1 Description of Operations

Four steps in tire manufacture are the production of rubber stock by compounding; tread and sidewall formation; tire cord, belt, and bead formation; and tire building, molding, and curing. These operations are described in detail in Table 9-1, which also indicates sources and levels of hydrocarbon or solvent emissions.

Compounding produces rubber stock from raw crumb rubber, extenders and curing agents. Mixing is accomplished in a Banbury Mixer and in roll mills. Rubber stocks in sheet form are extruded into tread and sidewall ribbons which are spray coated with solvent-borne cement. The cement-coated tread is conveyed to the tire-building area.

Tire cord, belt, and bead are formed by dipping wire and synthetic fabrics in solvent-borne rubber cement or latex. Solvent is vaporized in a drying oven. The tire materials are then coated or calendered with rubber. The tread, cord, belt, and bead are assembled to form a green (uncured) tire in the tire building operation. The green tire is coated inside and out with a solvent-borne release agent by spraying in a spray booth. The tire is cured or vulcanized in a mold using steam.

As indicated in Table 9-1, cementing, dipping, and green tire spraying are the significant sources of hydrocarbon emissions. About 97% of these emissions are solvents from three sources: green tire spraying (58% of emissions), dipping (30%), and tread cementing (9%). The remaining 3% of emissions are hydrocarbons vaporized during high temperature mixing, hot mill

TABLE 9-1. SOURCES AND LEVELS OF HYDROCARBON AND SOLVENT EMISSIONS FROM TIRE MANUFACTURING[1,2]

Operation	Description	Source and Description of Emissions	Emission Factor
Compounding, Mixing and Milling	Raw crumb rubber is mixed with fillers and extenders (carbon black and oil) antioxidants and accelerators at a high temperature in a Banbury mixer. The unreactive product is mixed with curing agents in roll mills to form a tacky sheet which is cooled and coated with a soapstone slurry	Mixing - vaporization of hydrocarbons due to high temperature of mixing Milling - heat from mechanical working produces volatile hydrocarbon emissions	3g/tire 2g/tire
Tread and Sidewall Formation	Rubber stock from the compounding operation is fed to a warm-up roller mill, then a strip feed mill. The thin strips of rubber stock are joined to form tread and sidewalls in an extruder. The tread/sidewall ribbon is cut and cooled and the ends are spray-coated with solvent-borne cement. The cement coated tread is conveyed to the tire building area	Extrusion - heat generated during extrusion causes vaporization of hydrocarbons Cementing - solvent evaporates during application of cement and as tread is conveyed to tire building area	2g/tire 28g/tire
Tire Cord and Belt Formation	Synthetic fabrics, steel wire, or fiberglass are dipped in rubber cement or latex. Excess dip is removed by vacuum suction or beater boxes. The coated material is treated in drying ovens where the remainder of the solvent evaporates. After dipping, the tire materials are friction coated with rubber in the calendering operation. The rubber stock is worked up in a series of warm up and strip feed mill rollers	Dipping - solvent from the cement or latex evaporates after application and in drying ovens Calendering - heated rollers are used to maintain rubber plasticity. Hydrocarbons are volatilized	100g/tire 2g/tire
Tire Bead Manufacture	Tire bead is a rubber covered copper ring made by extruding rubber onto a series of copper-plated steel wires. The bead is wrapped in calendered fabric		
Tire Building, Molding and Curing	The green tire components including cord, belt, bead, tread and sidewall are assembled as a cylinder on a round drum. The green tire is removed and sprayed inside and out with a solvent-borne release agent such as silicone oil. Spraying is done in a spray booth or under a hood. The green tires are cured or vulcanized in a mold using steam.	Spraying - Solvent evaporates during the spraying Curing - Solvent and other hydrocarbons may be vaporized during the high temperature curing operation	140g/tire 50g/tire

rolling, extruding and calendering. Other potential emissions not described in Table 9-1 include fugitive emissions and leaks from storage tanks. Although it was not stated in the literature, it seems likely that the emission factors in Table 9-1 are for uncontrolled sources.

9.2 Levels and Sources of Emissions in the Study Area

There are two tire manufacturing operations in the study area which produce hydrocarbon emissions from rubber processing. Emission rates from these facilities are summarized in Table 9-2. Total emissions from rubber processing in the study area were about 750 tons/year in 1975.

TABLE 9-2. HYDROCARBON EMISSIONS FROM RUBBER PROCESSING (TIRE MANUFACTURING) IN THE STUDY AREA

Emission Source	Hydrocarbon Emissions (tons/year) 1975	1977
Company RP-1 (Rutherford County)	181.5	-
Company RP-2 (Davidson County)	567.6	703

Data from permit files for Rutherford County indicate the emissions shown in Table 9-3 for the company RP-1's facility.

Table 9-4 summarizes data about company RP-2's emissions from Nashville Metropolitan Health Department files. The table describes the source of emissions for some of the emission points, but it is not clear how all the emissions are produced. Points EF-67 and 68 have the largest emission rates, so they are probably from green tire spraying.

TABLE 9-3. DATA ON HYDROCARBON EMISSIONS FROM COMPANY RP-1 COMPANY IN RUTHERFORD COUNTY (Source: County Permit Files)

Operation	Percent of Total Emissions	Hydrocarbon Emissions lb/Hr	Hydrocarbon Emissions Tons/Yr	Comments
Extrusion	2	1.0	4.4	Stream contains 5 ppm hydrocarbons, control methods are not used
Tire doper	83	34.5	151.1	Stream contains 3.5 ppm hydrocarbons, control methods not in use
Cement mix	13	10.7	23.4	Uncontrolled
Storage tanks	1	0.6	2.6	Uncontrolled
TOTAL		46.8	181.5	

Data reported by company RP-2[3] describing 1977 solvent consumption at the Nashville facility are summarized in Table 9-5. The 1977 solvent consumption rate was reported to be 1100 gal/day. Solvent emissions from RP-2's facility as tabulated in Nashville Metropolitan Health Department files are shown in Table 9-6.

In estimating the sources of hydrocarbon emissions from RP-2's facility it was assumed that the solvent consumption rates given for the operations listed in Table 9-5 are also indicative of hydrocarbon emission rates for those operations. The emissions from green tire spraying at RP-2's facility have been partially controlled by substituting water-based release agents for inside green tire spray. Outside spraying is still done with solvent-based release agents. Substitution of water-based tire spray is the only control method reported in use by company RP-2.

TABLE 9-4. DATA FROM NASHVILLE METROPOLITAN HEALTH DEPARTMENT FILES DESCRIBING EMISSION POINTS AND 1977 EMISSION RATES FOR COMPANY RP-2

Emission Point Designation	Description	Emission Rate (tons/year) 1977
EF 30	2500 cfm, 29 ppm hydrocarbons	3
EF 31	2500 cfm, 15 ppm hydrocarbons	1.5
EF 49	2455 cfm, 69 ppm hydrocarbons	6.9
EF 62	1150 cfm, 2400 ppm hydrocarbons	114.3
Stack 1	Emissions from tread cementing	19.8
Stack 2	Emissions from whitewall tread cementing	43.2
EF 67	Tire building emissions (3187 cfm, 1400 ppm hydrocarbons)	179.1
EF 68	Tire building emissions (3199 cfm, 1400 ppm hydrocarbons)	179.1
EF 69	Tire building emissions[a] (7020 cfm, 1400 ppm hydrocarbons)	136
Stack 10	Tire finishing emissions	20
TOTAL		703.0

[a] 15.6 lb/hr hexane, 18.3 lb/hr unidentified solvent

TABLE 9-5. SOLVENT CONSUMPTION BY END USE AT COMPANY RP-2's NASHVILLE FACILITY, 1977

Solvent End Use	Percent of Solvent Consumed
Outside green tire spray	47
Cementers	28
Tire room	12
Bead dip	11
Touch-up spray	2

TABLE 9-6. HYDROCARBON EMISSIONS BY TYPE OF SOLVENT FROM TIRE MANUFACTURING AT COMPANY RP-2

Solvent Type	Emissions (Ton/Yr)	
	1975	1977
Texol	188.7	246.2
Unidentified solvent	203.3	203.3
Hexane	175.1	175.1
TOTAL	567.1	624.6

9.3 Control Methods, Costs, and Cost Effectiveness

The three sources of solvent emissions in tire manufacturing are dipping cord, belt, or bead; sidewall and tread cementing; and green tire spraying with solvent-borne release agent.

Emissions from dipping wire and fabric in solvent-borne cement or latex occur when solvent is vaporized in drying ovens. Solvent also evaporates when excess latex or cement is removed in beater boxes or by vacuum lines. Applicable control techniques include carbon adsorption (90% efficient), thermal incineration (95% efficient) or catalytic incineration (90% efficient).

Control costs for incineration and carbon adsorption units on drying oven vents are given in Tables 9-7 and 9-8, respectively.[1] These data were generated in an EPA-funded study in which the control techniques were observed in operation at two plants. The incineration system was described as an off-the-shelf system available from a number of vendors. The carbon adsorption system was also described as state of the art technology. The cost data in Tables 9-7 and 9-8 are for facilities with slightly higher emission rates (400-500 tons/yr) from dipping operations than the facilities in the study area. The publication in which the cost data are given did not indicate the basis for calculation of annual operating costs or solvent recovery credit. The only indication of plant size was the hydrocarbon emission rate and the oven exhaust rate of 5000 scfm.

Emissions from tread cementing occur due to solvent evaporation during cement spraying or dipping and while the cemented tread is conveyed to the tire building area. The control system has an overall efficiency of 85%. It consists of collection equipment (90% efficient) and a carbon adsorption unit (95% efficient). Published costs for a collection system plus a dual bed carbon adsorption unit for an ubdertread cementing operation in which the cement is applied in a dip tank are shown in Table 9-9.[1] The solvent evaporation rate from this operation was 1340 kg/day while some 1200 kg/day was collected. Equivalent figures in tons/yr are shown in Table 9-10 to facilitate comparison with cost data for RP-2's plant. Published information concerning the basis for calculating operating costs and solvent recovery credit was unavailable.

Cost information for carbon adsorption controls on two treadline cementing units was also supplied by Company RP-2 for their Nashville facility.[3] Installed capital

TABLE 9-7. PUBLISHED COST OF INCINERATION FOR A TYPICAL FABRIC CEMENTING (TIRE CORD DIP) OPERATION

Incineration Device[1]	Capital Cost ($)	Annualized Operating Costs ($/year)	Control Cost, ($/ton of Hydrocarbons Removed)
No heat recovery			
Thermal	100,000	50,000	90
Catalytic	105,000	50,000	90
Primary heat recovery			
Thermal	20,000	35,000	63
Catalytic	120,000	35,000	63
Primary and secondary heat recovery			
Thermal	145,000	28,000[2]	50[2]
Catalytic	140,000	30,000[2]	55[2]

[1] Exhaust rate of 5000 scfm (2.3 Nm^3/s), temperature of 300°F (160°C), operation at 25 percent of the LEL. 555 tons HC/year controlled.

[2] Assumes that heat is recovered and used.

TABLE 9-8. PUBLISHED COST OF CARBON ADSORPTION FOR A TYPICAL FABRIC CEMENTING (TIRE CORD DIP) OPERATION

Control Cost[1]	Capital Cost ($)	Annualized Operating Cost (Credit) ($/year)	Control Cost (Credit) ($/ton of Hydrocarbons Removed)
No credit for recovered solvent	180,000	65,000	160
Recovered solvent credited at fuel value	180,000	38,000	90
Solvent credited at market value	180,000	(9,000)	(23)

[1] Exhaust rate of 5000 scfm (2.3 Nm^3/s), temperature of 175°F (80°C), operation at 25 percent of the LEL. 400 tons HC/year controlled.

TABLE 9-9. PUBLISHED COST OF CARBON ADSORPTION FOR A TYPICAL UNDERTREAD CEMENTING OPERATION

Control Case	Capital Cost, $	Annualized Operating Cost, (credit) $/Year	Control Cost (Credit) $/Ton of Hydrocarbons Removed
No credit for recovered solvent	180,000	65,000	160
Recovered solvent credited at fuel value	180,000	35,000	85
Solvent credited at market value	180,000	(10,000)	(24)

[1] Exhaust rate of 5000 scfm (2.3 Nm^3/s), temperature of 70°F, (21°C), operation at 25 percent LEL. About 400 tons/yr of hydrocarbons are controlled.

TABLE 9-10. HYDROCARBON EMISSION RATES FROM TREAD CEMENTING OPERATION DESCRIBED IN TABLE 9-9

		Emission Rate (tons/yr)	
Description of Emissions	Emission Rate (kg/day)	365 Operating Days Year	250 Operating Days Year
Uncontrolled	1340	528	368
Collected emissions	1206	485	331
After carbon adsorption	60 (+134 uncollected)	24 (+53 uncollected)	17 (+37 uncollected)

and annual operating costs are summarized in Table 9-11. Information supplied by RP-2 indicated that hydrocarbon emissions from the two cementer units are about 200 tons/yr (1977 emission rate). Assuming 95% control efficiency and 90% collection efficiency for the carbon adsorption unit these emissions could be reduced by 170 tons/yr for a cost effectiveness of $200/ton controlled. This factor was calculated from the net annual operating cost of $37,000/yr which includes credit for solvent recovered.

TABLE 9-11. CAPITAL AND ANNUAL COSTS ESTIMATES BY COMPANY RP-2 FOR CONTROL OF TREAD LINE CEMENTING EMISSIONS AT THEIR NASHVILLE FACILITY

Cost Item	Basis	Amount
Installed Capital Cost	Retrofit cost for carbon adsorption systems on two tread line cementers	$350,000
Depreciation	12% of capital	$ 29,000/yr
Utilities		$ 20,000/yr
Maintenance	5% of capital	$ 17,500/yr
Annual Cost		$ 66,500/yr
Solvent Recovery Credit	375 gal/day emitted (200 tons/yr)[a] 250 operating days $.45/gal 70% recovery	($ 29,500/yr)
Net Annual Cost		$ 37,000/yr

[a] Based on 250 operating days/year and a solvent density of 4.5 lb/gallon.

Solvent emissions from green tire spraying can be controlled by substituting water-based release agents for solvent-borne materials. Water based spray has been used to replace solvent base inside tire spray at RP-2's Nashville facility. This substitution resulted in a 20% reduction in total solvent consumption. Company RP-2 estimates the capital cost of implementing water-based outside green tire spray at less than $10,000. The estimated annual operating cost is $160,000 - $200,000/yr.[3] These high operating costs are attributed mainly to increased cost of spray materials. This information does not agree with literature sources, which indicate that the cost of water-borne release agents for this application is lower than the cost of solvent-borne release agents (Ref. 1, p. 61).

Table 9-12 summarizes control methods, efficiencies, and cost effectiveness for emissions from dipping, tread cementing, and green tire spraying. Table 9-13 shows estimated emissions from these three emission sources in the study area and the reductions that could be achieved by applying the controls listed in Table 9-12.

9.4 References

1. Environmental Protection Agency, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. Research Triangle Park, North Carolina, May 1977.

2. Snell, Foster D., Inc., "Assessment of Industrial Hazardous Waste Practices, Rubber and Plastics Industry," Draft Final Report, EPA Contract No. 68-01-3194, Office of Solid Waste Management Programs, February 1976.

3. Letter from Frank Luysterborghs (company RP-2) to Paul Bontrager (Metropolitan Health Department) dated 13 June 1977.

TABLE 9-12. CONTROL METHODS AVAILABLE FOR HYDROCARBON EMISSIONS FROM RUBBER TIRE MANUFACTURING

Emission Source	Control Method	Control Efficiency (%)	Cost Effectiveness ($1000/ton)
Dipping cord, belt or bead	Carbon adsorption	90	.16-(.02)[a]
	Thermal incineration	95	.05-.09[b]
	Catalytic incineration	90	.05-.09[b]
Tread cementing	Collection equipment	90	.08-(.02)[c]
	Carbon adsorption unit	95	
Green Tire Spraying	Substitution of water-borne release agents	100	0.7[d]

[a] lower values for case with no credit for recovered solvent, higher value for case with solvent credited at market value (see Table 9-7)

[b] lower value for case with no heat exchange, higher value for case with primary and secondary heat exchange and heat reuse (see Table 9-8)

[c] lower value for case with no credit for recovered solvent, higher value for case with solvent credited at market value (see Table 9-9). Company RP-2's estimate is $200/ton controlled.

[d] calculated from company RP-2 cost data assuming 266 tons/yr controlled

TABLE 9-13. POTENTIAL REDUCTION IN 1975 HYDROCARBON EMISSIONS FROM RUBBER PROCESSING IN THE STUDY AREA USING SELECTED CONTROL METHODS

Emission Source	Estimated Emission Rate (tons/yr) RP-1[a]	RP-2[b]	Total	Control Method	Efficiency (%)	Emission Remaining After Controls (tons/yr)
Dipping bead, cord, and belt	4.4 (extruder)	62	66	carbon adsorption	90	7
Green tire spray	151.0 (tire doping)	266 (outside spray)	417	substitute water based release agent	100	0
Tread cementing	23.4	159	182	collection plus carbon adsorption	85	27
Other	2.6 (storage tank)	79 (tire finishing, touch up spray)	83	none specified		83
			748			117

[a] reported by company RP-1

[b] estimated from (1) reported total solvent consumption in gallons/day, 4.5 lb/gallon solvent density and (2) reported percent solvent consumed given in Table 9-4.

10.0 HYDROCARBON EMISSIONS FROM DRY CLEANING

10.1 Description of Operations

Dry cleaning uses organic solvents to clean soiled fabrics. The process involves three steps: 1) one or more washes (baths) in solvent by agitation and rinsing, 2) extraction of excess solvent by spinning; and 3) tumble drying in an air stream. Either the transfer process or the dry-to-dry process is used. Transfer machines use separate equipment for washing and drying. After washing and extraction, the fabrics must be transferred to the dryer. In dry-to-dry operations, washing, extraction, and drying are performed in the same machine.

The dry cleaning industry uses two types of solvents. Petroleum solvents are combustible, kerosene-like mixtures with approximate chemical compositions of 46% paraffins, 42% naphthenes, and 12% aromatics. The second type, synthetic solvents, includes non-flammable halogenated hydrocarbons such as perchloroethylene (perc) and 1, 1, 2-trichlorotrifluoroethane (fluoro). Petro-solvents are used only in transfer type machines, while synthetic solvents can be used in either transfer or dry-to-dry machines. Perchloroethylene is used mainly in transfer units, and all fluorocarbon operations are in dry-to-dry machines.

Dry cleaning is done in industrial, commercial, and coin-operated facilities. Most industrial facilities use petroleum solvents while the typical commercial or coin-operated facility employs synthetic solvents. Currently, fluorocarbon solvent is used only in commercial and coin-op facilities.

Figures 10-1 through 10-3 illustrate the processing steps and equipment used in dry cleaning plants employing petroleum, perc, and fluoro solvents, respectively.

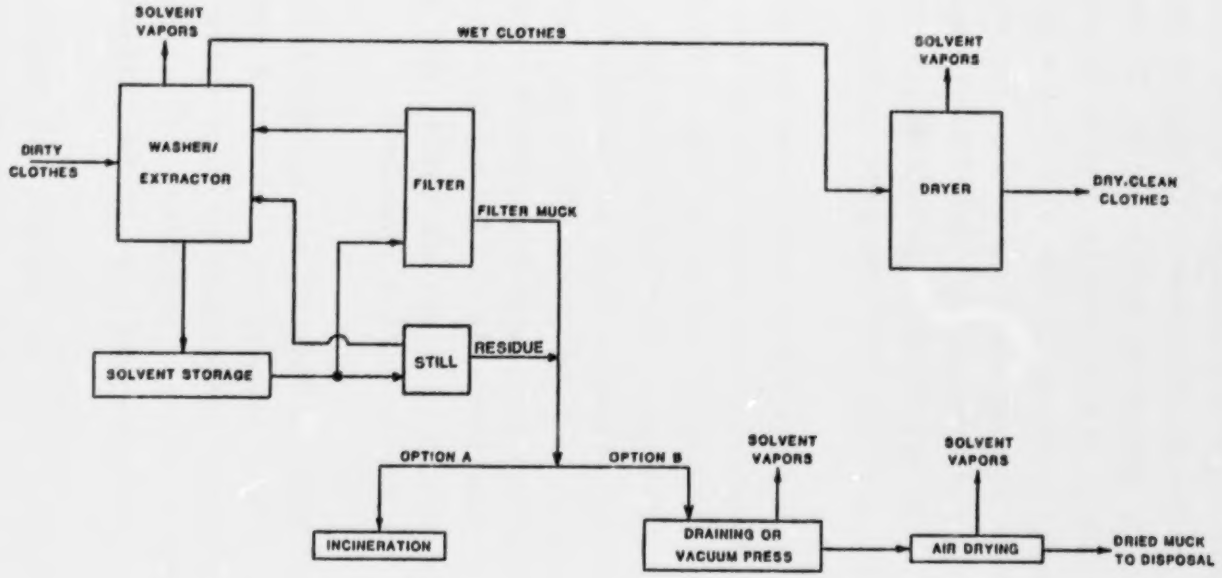

SOLVENT VAPORS
WET CLOTHES
SOLVENT VAPORS
DIRTY CLOTHES
WASHER/ EXTRACTOR
FILTER
FILTER MUCK
DRYER
DRY.CLEAN CLOTHES
STILL
RESIDUE
SOLVENT STORAGE
OPTION A
OPTION B
SOLVENT VAPORS
SOLVENT VAPORS
INCINERATION
DRAINING OR VACUUM PRESS
AIR DRYING
DRIED MUCK TO DISPOSAL

Figure 10-1. Petroleum-Solvent based dry cleaning plant.

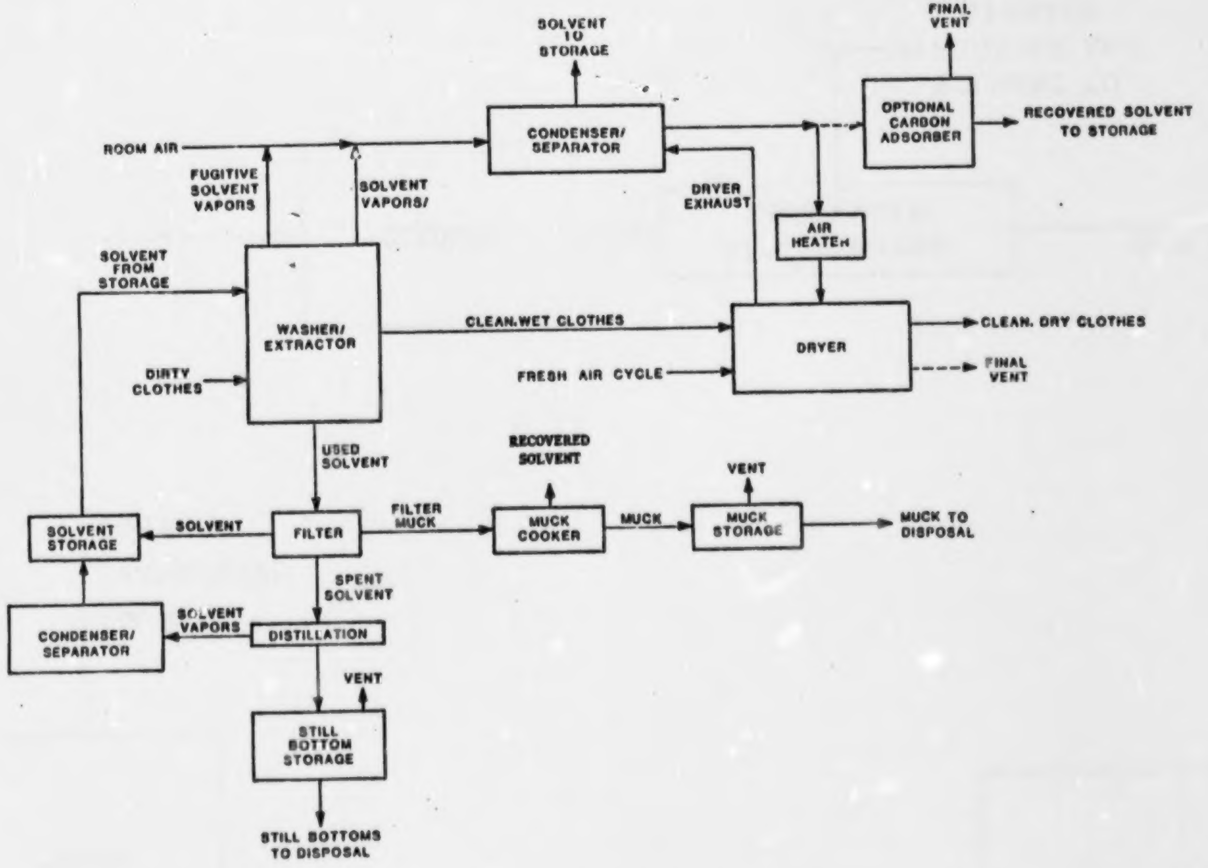

SOLVENT TO STORAGE
FINAL VENT
ROOM AIR
CONDENSER/ SEPARATOR
OPTIONAL CARBON ADSORBER
RECOVERED SOLVENT TO STORAGE
FUGITIVE SOLVENT VAPORS
SOLVENT VAPORS/
DRYER EXHAUST
AIR HEATER
SOLVENT FROM STORAGE
WASHER/ EXTRACTOR
CLEAN,WET CLOTHES
DRYER
CLEAN, DRY CLOTHES
DIRTY CLOTHES
FRESH AIR CYCLE
FINAL VENT
USED SOLVENT
RECOVERED SOLVENT
VENT
SOLVENT STORAGE
SOLVENT
FILTER
FILTER MUCK
MUCK COOKER
MUCK
MUCK STORAGE
MUCK TO DISPOSAL
SPENT SOLVENT
CONDENSER/ SEPARATOR
SOLVENT VAPORS
DISTILLATION
VENT
STILL BOTTOM STORAGE
STILL BOTTOMS TO DISPOSAL

Figure 10-2. Flow diagram for a dry cleaning plant using perchloroethylene solvent.

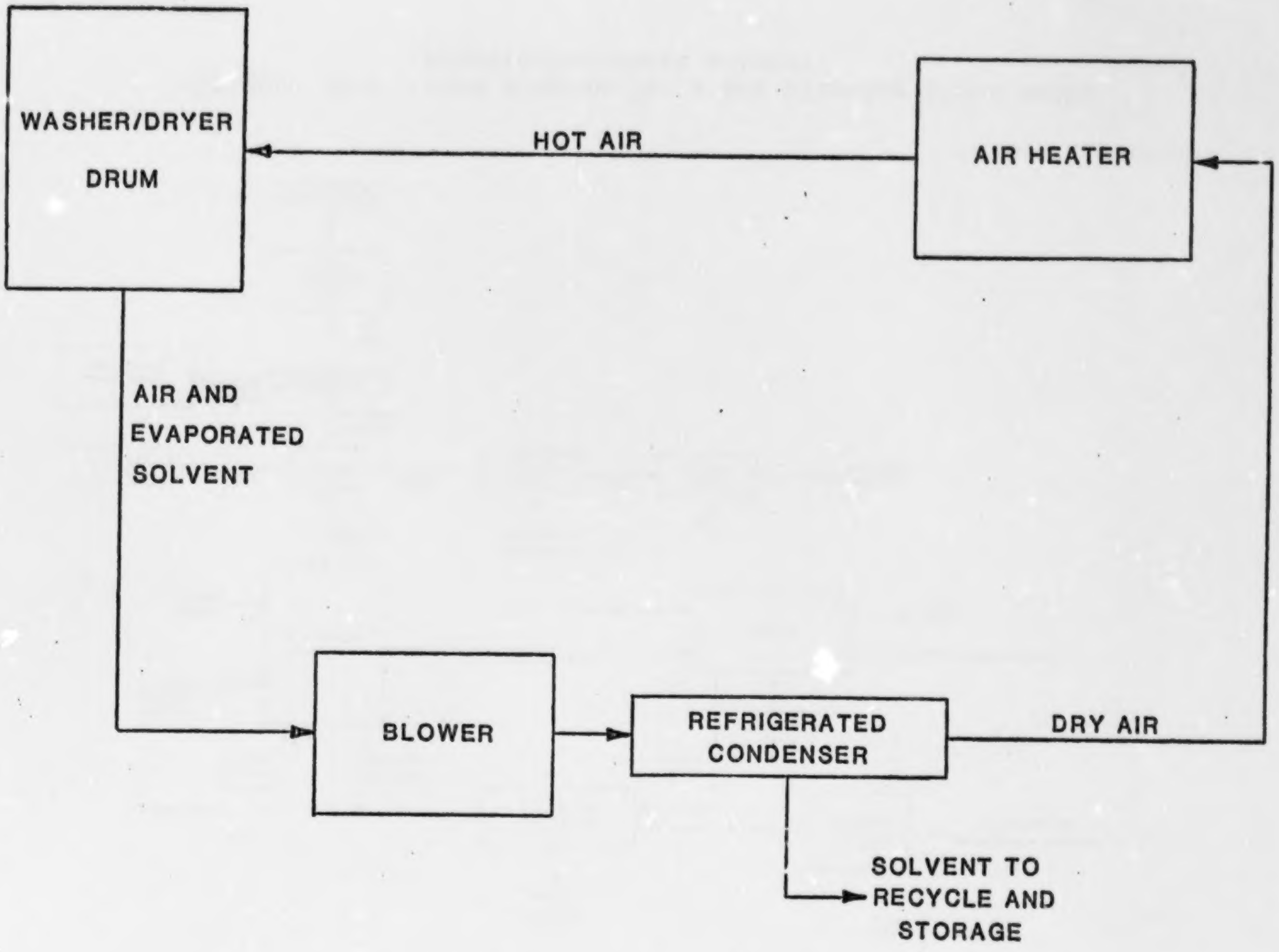

WASHER/DRYER DRUM
HOT AIR
AIR HEATER
AIR AND EVAPORATED SOLVENT
BLOWER
REFRIGERATED CONDENSER
DRY AIR
SOLVENT TO RECYCLE AND STORAGE

Figure 10-3. Flow diagram for dry cleaning plant using fluorocarbon solvent.

Solvent emissions from dry cleaning plants occur during washing, extracting, and drying steps and during solvent recovery operations. Equipment leaks, valves, seals, and covers and vapor loss during storage and storage tank loading are other sources of emissions.

Solvent emissions associated with the wash-rinse-extraction steps are of three kinds. Vapor or liquid can be released when the door is not properly sealed or is opened unnecessarily. These emissions are usually very small and are more significant in transfer machines than in dry-to-dry machines. Emissions can also occur in transfer operations due to dripping from fabrics during transfer to the dryer. The major source of emissions during the washing-extraction cycle occurs when extraction is incomplete. Incomplete extraction is caused by too short a cycle or poorly maintained equipment. Slipping drive belts reduce the speed of spinning and result in less effective extraction. Solvent left in fabric is vaporized at the drying step.

In the drying operation, essentially all unextracted solvent is driven out of the fabrics by a warm gas stream. Dryers are the major source of emissions in petroleum operations and are also significant in perc operations. The major variable in both operations is the efficiency of extraction. Because fluorocarbon solvents are expensive, fluorocarbon machines must show low solvent consumption to be cost competitive with perc or petroleum machines. Consequently, all fluorocarbon machines are of the dry-to-dry type and all have built-in control devices, either a refrigeration/condensation system or a dual canister carbon adsorber.

Solvent recovery operations are a source of emissions in all dry cleaning facilities. The dissolved and suspended materials from fabrics must be removed to regenerate solvents for reuse. The solvent is filtered in cartridges of various types. Most large facilities also have solvent distillation systems to purify and recover dirty solvent. Distillation residues containing solvent are usually discarded. Filter muck and expanded filter cartridges can be discarded or processed to recover solvent. Filter muck can be processed in a muck cooker which vaporizes residual solvent. Spent cartridges can be treated in the dryer.

Examples of causes for solvent losses given by an equipment manufacturer, were the following.[2]

Sources of liquid loss and leaks include:

a) Hose connections, unions, coupling and valves.
b) Machine door gasket and seating.
c) Filter head gasket and seating.
d) Pumps.
e) Base tanks and storage containers.
f) Water separators (solvent lost in water due to poor separation).
g) Filter sludge recovery (solvent lost in sludge by improper recovery).
h) Distillation unit.
i) Divertor valves.
j) Saturated lint from lint basket.
k) Cartridge filters.

Sources of vapor loss and leaks include:

a) Deodorizing and aeration valves on dryers (the seals on these valves need periodic replacement).
b) Air and exhaust ductwork (solvent lost through tears in duct).

c) Lint screens and bags, fan blades and condensers can adversely affect capture systems if they are clogged or caked with lint.

d) Overloading and underloading can increase losses. Overloading makes drying difficult. Underloading is self-defeating since most losses are fixed in the system.

e) Doors left open are problems. Leaks in the system should be confined to the closed washer and/or dryer if possible.

f) Inefficient extraction due to overloading or loose belts can overload the dryer.

g) Button traps and lint baskets should be opened only as long as necessary.

Table 10-1 shows the percentage of losses from six points in dry cleaning operations using the three solvent types.

TABLE 10-1. PERCENTAGE OF SOLVENT LOSSES FROM SIX POINTS IN DRY CLEANING OPERATIONS[2]

Type of Loss	Petroleum Solvent	Perc Solvent	Fluoro Solvent
Washer	-*	4% - 5%	0
Dryer	59% - 63%	14% - 23%	0
Filter Muck	26% - 29%	54% - 65%	N/A
Filter Cartridge	2% - 4%	5% - 8%	20% - 40%
Still Residue	5% - 6%	6% - 7%	<20%
Miscellaneous Losses	5% - 6%	5% - 8%	20% - 60%

*Included in Dryer Emissions

10.2 Levels and Sources of Emissions

The Nashville area has an estimated 648 tons/yr solvent emissions from dry cleaning. These baseline emissions account for almost 4% of the total stationary source hydrocarbon emissions in the area. The baseline emission rate was estimated in a previous study using the weighted emission factors shown in Table 10-2.[3,5] The emission factors are in units of lb solvent/ton of clothes cleaned based on type of solvent and extent of controls in use. Weighting factors are based on estimates of the percentage of clothes cleaned with each type of solvent. The study assumed that in moderate climates each person cleans 18 lbs of clothes per year. County emission rates were estimated using the following formula:

$$\text{weighted emission factor} \times \frac{\text{quantity of clothes cleaned}}{\text{person-year}} \times \text{county population}$$

The estimated emission rates for each type of solvent and the number of dry cleaning facilities in each county are summarized in Table 10-3. Data on the number of dry cleaning facilities were obtained from local agencies.

10.3 Control Technology

Presently, few controls are used in petroleum solvent plants to prevent solvent loss. The level of emissions from perc plants varies greatly due to equipment differences and variations in solvent recovery methods. Carbon adsorption is currently used in some perc plants. Fluorocarbon solvent emissions are low because all machines are of the dry-to-dry type with a closed drying system which has no vent. Table 10-4 shows potential control methods for dry cleaning operations.[2]

TABLE 10-2. EMISSION FACTORS USED TO ESTIMATE SOLVENT EMISSIONS FROM DRY CLEANING OPERATIONS IN THE STUDY AREA[3,5]

Solvent, Controls	Emission Rate $\left(\frac{\text{lb solvent}}{\text{ton of clothes cleaned}}\right)$	Weighting Factor (% of clothes cleaned with solvent)	Weighted Solvent Emission Rate (lb/ton of clothes)
Petroleum, uncontrolled	250	50	152.5
Synthetic, uncontrolled	210	12.5	35.6
Synthetic, average controls	95	37.5	26.3
		OVERALL EMISSION FACTOR	214.4

TABLE 10-3. SUMMARY OF 1974 HYDROCARBON EMISSIONS FROM DRY CLEANING OPERATIONS IN THE STUDY AREA

County	No. of Dry Cleaning Establishments	Hydrocarbon Emissions (tons/year)			
		Petroleum Solvents	Synthetic Solvents, Average Controls	Synthetic Solvents, Uncontrolled	Total
Davidson	152	308	72	54	434
Rutherford	18	45	11	8	64
Sumner	25	47	11	8	66
Williamson	10	30	7	5	42
Wilson	9	30	7	5	42
Total	214	460	108	80	648

TABLE 10-4. POTENTIAL AND APPLIED CONTROL TECHNIQUES FOR DRY CLEANING PLANTS[2]

	Plant type		
	Petroleum	Perc	Fluorocarbon
Carbon adsorption	X	X[a]	X
Housekeeping	X[a]	X[a]	X[a]
Incineration	X	NA	NA
Non-vented systems	X	X	X[a]
Refrigeration/condensation	X	X	X[a]
Waste solvent treatment	X	X[a]	X[a]

[a]Commonly used technique

NA = Not available

Improvement of the housekeeping and operating practices can be used to control solvent emissions by preventing some of the miscellaneous and dryer emissions and most of the solvent recovery emissions. These techniques are already in use to some extent. One report concluded that "the mileage (lbs of fabric cleaned/drum of solvent) obtained in a perc plant appears to be more strongly affected by the competence of the operator than by any other factor[4]." It also stated the International Fabric Institute (IFI) gives most of the credit for either poor mileage performance or exceptional mileage performance to the plant operator[4] for perc plants. The primary factor governing solvent consumption in petroleum plants was reported to be extraction efficiency.

Improvement in housekeeping and operating practices includes rules for equipment maintenance and operation based on manufacturers' recommendations plus better training in the handling of organic solvents and a system of record keeping to indicate solvent mileage. Improved operating practice includes operator care in controlling door openings and extraction cycle time; detection of liquid leaks through observation of colored residues on floors and equipment; detection of vapor leaks by instrument, smell, or soap-and-water tests at connections; and record keeping and reporting systems for equipment maintenance.

Improvements in solvent recovery operations can also be made. Filter-muck should be cooked to vaporize excess hydrocarbons. Treating cartridges in the dryer (without tumbling) when dryer emissions are controlled is good practice. Residues from the filter and the stills should be checked to make sure they are not highly diluted and then they should be disposed of using a method that does not allow evaporation of residual solvent. Equipment for collection of the muck cooking and cartridge drying emissions is available.

Carbon adsorption was recommended as the add-on control method of choice for petroleum and perc plants in a study to develop new source performance standards for the dry cleaning industry.[4] Table 10-5 shows emission rates measured at dry cleaning plants with various levels of control. The differences in emission rates for "poor, typical, or good" uncontrolled plants are a result of housekeeping practices. This table shows the overall control efficiency that is achieved in practice with carbon adsorption units at dry cleaning facilities. Although the hydrocarbon removal efficiency of a carbon adsorption unit is very high, the overall control efficiency achieved with carbon adsorption at dry cleaning plants is lower for two reasons. First, the carbon adsorption unit treats only the emissions from the dryer exhaust. Second, some of the emissions are prevented by improved housekeeping practices. Depending on housekeeping practices, carbon adsorption reduced overall emissions at perc plants from 45% (good housekeeping) to 85% (poor housekeeping). Measured reductions at petroleum solvent plants were from 44% (good housekeeping) to 63% (average housekeeping).

TABLE 10-5. MEASURED EMISSION RATES AND SOLVENT CONSUMPTION AT DRY CLEANING PLANTS WITH VARIOUS LEVELS OF CONTROL[4]

Solvent Type	Control Technique	Emission Rate[a]	Mileage[b]
Perchloroethylene	Uncontrolled - Poor	486	2,900
	Uncontrolled - Typical	203	6,940
	Uncontrolled - Good	128	11,000
	Carbon Adsorber - Typical	168	8,369
	Carbon Adsorber - Good	94	15,000
	Carbon Adsorber - Best	70	20,000+
Petroleum	Uncontrolled - Average	468	1,456
	Uncontrolled - Good	310	2,200
	Carbon Adsorber - Good	173	3,935
Fluorocarbon	Refrigeration - Typical	60	22,800
	Refrigeration - Good	37	37,000

[a] Units are pounds of solvent per ton of fabrics cleaned.

[b] Units are pounds of clothes cleaned per 52-gallon drum of solvent.

Table 10-6 shows the sources and typical levels of emissions from model plants, the control methods selected for each emission source, and the estimated emission rates after controls are applied.[2] The information in Table 10-6 was used to calculate the control efficiencies summarized in Table 10-7. Table 10-7 shows that for petroleum plants, improved housekeeping can be used to treat 36 percent of the total emissions with 70 percent control efficiency to give a 25 percent reduction in total emissions. The remaining 64 percent of the total emissions can be treated by carbon adsorption with 84 percent control efficiency. A 79 percent reduction in total petroleum solvent emissions can be achieved using both improved housekeeping and carbon adsorption. For perc plants, improved housekeeping can be used to treat 42 percent of the emissions with 40 percent control efficiency to give a 17 percent reduction in total emissions. Carbon adsorption plus improved housekeeping will reduce total emissions by 67 percent.

Table 10-8 shows how hydrocarbon emissions in the study area could be reduced by improved housekeeping and operating practices and installation of carbon bed adsorbers. Improved housekeeping and operating practices would reduce total solvent emissions to about 500 tons/year, a 33 percent reduction of dry cleaning solvent emissions in the study area. The use of both improved housekeeping and carbon adsorption would reduce total emissions to about 160 tons/year, a 75 percent reduction in total dry cleaning solvent emissions.

10.4 Capital and Operating Costs

Capital and operating costs for improved housekeeping procedures are negligible[2,4] and are readily paid for by the increased efficiency in solvent usage. The costs involved are

TABLE 10-6. CONTROL TECHNIQUES AND SOLVENT EMISSION LEVELS FOR MODEL DRY CLEANING PLANTS[2]

Type of Plant	Source	Emission Level $\left(\frac{\text{kg Solvent}}{\text{100 kg fabric cleaned}}\right)$	Control Technique	Controlled Level $\left(\frac{\text{kg Solvent}}{\text{100 kg fabric cleaned}}\right)$
Petroleum	Dryer evaporation	18	Carbon adsorption, incineration	2-3
	Filter muck retention	6	Cartridge filters, centrifugal separation, vacuum distillation, incineration	0.5-1.0
	Still residue	1	Longer distillation periods	0.5-1.0
	Miscellaneous[a]	3	Good housekeeping	1
Perchloroethylene	Washer	1	Carbon adsorber	0.5-1.0
	Dryer	6	Carbon adsorber	
	Filter muck retention	1.5	Cartridge filters, longer cooking times	0.5-1.0
	Still residue	1.5	Longer distillation	0.5-1.0
	Miscellaneous[a]	2	Good housekeeping	1
Fluorocarbon	Cartridge filters	0.5-1	None needed	0.5-1.0
	Still residue	0.5		0.5
	Miscellaneous[a]	1-2		1-2

[a] Leaks from pumps, valves, gaskets, etc.

TABLE 10-7. CONTROL EFFICIENCIES OF IMPROVED OPERATING AND HOUSEKEEPING PRACTICES AND CARBON ADSORPTION AT MODEL DRY CLEANING OPERATIONS[2]

Type of Plant and Source of Emissions	Uncontrolled Emissions[a] $\frac{\text{kg solvent}}{\text{100 kg fabric}}$	Control Method	Controlled Emissions[a] $\frac{\text{kg solvent}}{\text{100 kg fabric}}$	Control Efficiency (%)
Petroleum				
washer, dryer	18	Carbon Adsorption	3	84[b]
filter, still, misc.	10	Improved housekeeping and operating practices	3	70
Perchloroethylene				
washer, dryer	7	Carbon adsorption	1	86[c]
filter, still, misc.	5	Improved housekeeping and operating practices	3	40

[a] See Table 10-6.

[b] $\frac{\text{controlled emissions}}{\text{total emissions}} = \frac{21}{28} = 79\%$ reduction in total emissions

[c] $\frac{\text{controlled emissions}}{\text{total emissions}} = \frac{8}{12} = 67\%$ reduction in total emissions

TABLE 10-8. REDUCTION IN SOLVENT EMISSIONS FROM DRY CLEANING OPERATIONS IN THE STUDY AREA WITH IMPROVED HOUSEKEEPING PRACTICES AND CARBON ADSORPTION

Emission Source	Uncontrolled Emission Rate (tons/year)	Control Method	Percent Reduction in Total Emissions	Emission Rate After Controls (tons/year)
Petroleum solvent	460	Improved housekeeping and operating practices	25	345
		Improved housekeeping plus carbon adsorption	79	97
Synthetic Solvents	188	Improved housekeeping and operating practices	17	156
		Improved housekeeping plus carbon adsorption	67	62

for better flanges and hose connections, operator training and increased supervision.

Capital and operating costs for carbon adsorption controls for model industrial and commercial dry cleaning facilities employing petroleum and synthetic (perc) solvents have been estimated[2]. Model plant parameters used in the cost estimates are shown in Table 10-9, and the costs are summarized in Table 10-10. Since data on typical plant sizes in the study area are unavailable, it is not known whether the model plants are representative of those in the study area. However, the literature indicates they are typical of the industry in general.[2]

10.5 Economic Impact

The economic impact of reducing dry cleaning solvent emissions through improved housekeeping practices and installation of carbon adsorbers has been investigated.[4] The impact for both new facilities and for addition of a new dry cleaning machine equipped with a carbon adsorber at existing facilities was estimated. The results are described for commercial, industrial, and coin-op facilities in the following sections.

10.5.1 Commercial Plants Using Perchloroethylene Solvents

The incremental costs of carbon adsorption controls for a new facility and an existing facility were estimated. Table 10-11 shows that the cost of the adsorber was 4.6% (average) of total plant capital cost for a new facility and 17% (average) of plant expansion capital cost for an existing facility to which a new 40-lb cleaning machine with carbon adsorber was added. The net annualized costs in Table 10-11 show that the controls result in a net savings for commercial facilities. The economic impact

TABLE 10-9. MODEL PLANT PARAMETERS USED IN ESTIMATING COST OF CONTROL MEASURES FOR DRY CLEANING FACILITIES[2]

Plant Parameter	Petroleum Solvent		Perchloroethylene Solvent		
	Commercial Plant	Industrial Plant	Coin-Op Plant	Commercial Plant	Industrial Plant
Washer load capacity (kg)	27	136	2 @ 3.6	23	136
No. of loads/yr	900	3000	525	2113	5007
Dryer exhaust flow (scfm)	1000	5100	91	242	3548
Dryer exhaust temp (°C)	77	77	24	24	24
Uncontrolled solvent emissions (tons/yr):					
washer/dryer	4.8	81	0.29	3.7	52
filter muck	1.6	27	0.06	0.8	11
still residue and misc.	1.1	18	0.15	1.9	26
Total	7.5	126	0.5	6.4	89
Solvent cost ($/lb)	.095	.095	0.21	0.21	0.21

TABLE 10-10. CAPITAL AND OPERATING COSTS AND COST EFFECTIVENESS FOR RETROFIT CARBON ADSORPTION SYSTEMS FOR CONTROL OF SOLVENT EMISSIONS FROM DRY CLEANING OPERATIONS (Reference 2)

Type of Dry Cleaning Facility and Solvent	Rate of Solvent Emissions (Uncontrolled) (tons/year)	Solvent Recovered (tons/year)	Capital Cost of Installed Adsorber ($1,000)	Annual Operating Cost ($1000/yr)				Cost Effectiveness $1000/ton controlled
				Capital Charges[1]	Direct Operating Costs[2]	Solvent Recovery (Credit)[3]	Net Operating Cost	
Industrial[4] (Petroleum)	126	78.5	74.9	12.9	4.3	(14.9)	2.3	.03
Commercial[4] (Petroleum)	7.5	4.7	17.65	3.05	1.0	(0.9)	3.15	0.67
Industrial[5] (Perc)	89	41	9.45	1.63	0.5	(17.2)	(15.1)	(0.37)
Commercial[5] (Perc)	6.4	3.7	4.3	0.744	0.2	(1.55)	(0.6)	(0.16)
Coin-Op[5] (Perc)	0.5	0.3	7.7	1.32	0.4	(0.13)	1.59	5.3

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[1] 10% interest, 15-year depreciation plus 4% of capital for taxes, insurance, and administration. (Costs in 1977 dollars)

[2] 2% of capital for maintenance plus cost of labor, utilities, and materials.

[3] Solvent credited at $0.095/lb for petroleum solvent and $0.21/lb for perchloroethylene.

[4] Controls include improved housekeeping for control of still residue and miscellaneous emissions and carbon adsorption for control of vented washer/dryer emissions (83% recovery). Solvent recovery based on emission factors in Tables 10-6 and 10-7.

[5] Controls include carbon adsorption for control of vented washer/dryer emissions. Solvent recovery based on emission factors in Tables 10-6 and 10-7.

TABLE 10-11. CAPITAL INVESTMENT AND ANNUALIZED COST FOR CARBON ADSORPTION ON NEW AND EXISTING COMMERCIAL DRY CLEANING FACILITIES USING PERCHLOROETHYLENE SOLVENT[4]

	New Plant		Expansion of Existing Plant	
Cost Item	Dry to Dry Machine	Transfer Machine	Dry-to-Dry Machine	Transfer Machine
Total cost, $ (Uncontrolled)	75,375[a]	69,375[a]	27,600[b]	21,500[b]
Cost of Adsorber, $	3,300	3,300	3,300	3,300
Installation Cost, $	-	-	825	825
Total Cost, $ (Controlled)	78,675	72,675	31,725	25,625
Incremental Control Cost (%)	4.4	4.8	14.9	19.1
Capital Charges, $	526	526	658	658
Maintenance and Operating $	165	165	165	165
Solvent (Credit) $	(1,456)	(1,456)	(1,456)	(1,456)
Net Annualized Cost (Credit), $	(765)	(765)	(633)	(633)

[a] Total Plant Cost

[b] Total Expansion Cost

analysis revealed a weak economic condition in the commercial dry cleaning sector. It was concluded that the 4.6% incremental cost of control for new plants would not prevent the construction of a new plant, and that the net savings to the dry cleaner from solvent credit would provide an increase in profits with no effect on prices. For existing commercial perchloroethylene plants, it was concluded that the 15 to 19% incremental investment cost of control could prevent operators from adding capacity. If capacity were added, annual operating expenses would be reduced and there would be no expected effect on prices.

10.5.2 Industrial Plants Using Perchloroethylene and Petroleum Solvents

Economic impact analysis for housekeeping and carbon adsorption controls on new and existing industrial laundry/dry cleaning facilities were also done. Table 10-12 summarizes estimated capital and net annualized costs. From these results and from the finding that the industrial sector is an economically healthy industry, it was concluded that investment costs for new or existing perchloroethylene plants would not discourage new plant construction or existing plant expansion. Carbon adsorption controls reduce annualized costs for perchloroethylene plants, but the reduction is small in comparison with investment costs and average annual receipts. As a result, no effects on pricing policies are expected.

Installation of new facilities or expansion of existing facilities with petroleum solvent dry cleaning equipment will be less likely because the investment cost for control is a significant percentage of plant cost or expansion cost. For existing plants, the cost of petroleum plant modifications is more than 50 percent greater than the equivalent perchloroethylene plant

TABLE 10-12. CAPITAL INVESTMENT AND ANNUALIZED COSTS FOR CARBON ADSORPTION ON NEW AND EXISTING INDUSTRIAL LAUNDRY/DRY CLEANING FACILITIES USING PERCHLOROETHYLENE AND PETROLEUM SOLVENTS[4]

Cost Item	New Plant		Expansion of Existing Plant	
	Perchloroethylene	Petroleum	Perchloroethylene	Petroleum
Total Cost, $ (Uncontrolled)	833,000[a]	818,500[b]	139,500[c]	128,500[c]
Installed Cost of Adsorber, $	7,000	90,000	7,500	94,000
Total Cost, $ (Controlled)	840,000	908,500	147,000	222,500
Incremental Control Cost (% of dry cleaning equipment cost)	5.1	72.9	5.1	73.2
(% of total equipment cost)	0.84	11.0	NA	NA
Capital Charges, $	1,116	14,344	1,196	14,982
Maintenance and Utilities, $	425	5,508	425	5,508
Solvent (Credit), $	(7,280)	(19,505)	(7,280)	(19,505)
Net Annualized Cost (Credit), $	(5,739)	347	(5,659)	985

[a] Complete investment cost for new industrial plant including two 600-lb. laundry machines and a 250-lb. dry cleaning machine with still and reclaiming dryer

[b] Complete investment cost for new industrial plant including two 600-lb. laundry machines and a 500-lb. dual phase cleaning machine with vacuum still and dryer

[c] Total expansion cost for the addition of one new cleaning machine, dryer, and boiler

modification. As a result, most operators would choose perchloroethylene machines rather than petroleum machines for plant modifications.

10.5.3 Coin-Operated Plants Using Perchloroethylene Solvents

Table 10-13 shows capital investment and annualized costs for carbon adsorbers on a model coin-operated dry cleaning plant. While investment costs for control are 12.8 percent of total plant cost, net annualized costs are reduced by a moderate amount. No change in pricing structure would be anticipated due to installation of control equipment in a new or existing plant. Since

TABLE 10-13. CAPITAL INVESTMENT AND ANNUALIZED COSTS FOR CARBON ADSORPTION ON COIN-OPERATED DRY CLEANING PLANTS USING PERCHLOROETHYLENE SOLVENTS[4]

Item	Cost
Total Installed Cost of Uncontrolled Plant (four 25-lb. dry-to-dry machines with cartridge filters and stills)	$47,250
Installed Cost of Carbon Adsorber	$ 6,050
Total Cost of Controlled Plant	$53,330
Incremental Cost of Control	12.8%
Capital Charges	$ 964/yr
Maintenance and Operating Cost	$ 303/yr
Solvent Credit	($1,677/yr)
Net Operating Cost (Credit)	(410 $/yr)

fluorocarbon solvent plants require a substantially lower investment cost than equivalent perchloroethylene plants, fluorocarbon equipment might be selected over perchloroethylene equipment for new or expanded facilities.

10.6 References

1. National Air Pollution Control Administration, Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources. Washington, D.C., 1970.

2. Environmental Protection Agency, Emission Standards and Engineering Division, Chemical and Petroleum Branch, Control of Volatile Organic Emissions from Dry Cleaning Operations, draft report. Research Triangle Park, North Carolina, April, 1977.

3. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, 2nd ed. with Supplements, AP-42, Research Triangle Park, N.C., 1973.

4. McCoy, Billy C., Study to Support New Source Performance Standards for the Dry Cleaning Industry, final report. EPA 450/3-76-029, EPA Contract No. 68-02-1412, Task Order No. 4. Vienna, Virginia, TRW, Inc., Energy Systems Group, Environmental Engineering Division, May, 1976.

5. PEDCo Environmental Specialists, Inc. Hydrocarbon Area Source Emission Inventory for Cheatham, Davidson Robertson, Rutherford, Sumner, Williamson and Wilson Counties, Tennessee. EPA Contract No. 68-02-1375, Task Order No. 9. Cincinnati, Ohio. July, 1976.

11.0 HYDROCARBON EMISSIONS FROM DEGREASING

11.1 Description of Operations

Degreasing removes soils from metal articles before further processing or assembly. Types of equipment used are cold cleaners, open top vapor cleaners, and conveyorized cleaners. A broad spectrum of organic solvents is available, such as petroleum distillates, chlorinated hydrocarbons, ketones, and alcohols. Metal workpieces are cleaned with organic solvents because water or detergent solutions dry slowly, cause rusting, and have a relatively low solubility for greases. The solvents most commonly used are the chlorinated hydrocarbons.

Cold cleaners are the simplest and least expensive type of degreaser; consequently they are also the most common. They are used for the removal of oil base impurities from metal parts in a batch loaded procedure that includes spraying, brushing, flushing, and immersion. The cleaning solvent is often at room temperature, although it may be slightly heated. The solvent never reaches its boiling point. There are several methods for materials handling in cold cleaning operations. Manual loading is used for simple, small-scale cleaning operations. Batch loaded, conveyorized systems are more efficient for complex, large-scale operations.

The open top vapor degreaser operates by condensation of vaporized solvent on the surface of the metal parts. The soiled parts are batch loaded in the solvent-rich vapor zone of the unit. Solvent vapors condense on the cooler surface of the metal parts. Conveyorized degreasers operate on the same principles as open top degreasers; the only difference is in material handling. In conveyorized cleaners, some parts may be dipped but manual handling of parts is mostly eliminated.

Solvent losses occur in the following ways:

1) Diffusion and evaporation occurs at the opening where articles enter or leave the cleaner;
2) Solvent is carried out as parts are removed;
3) Splashing of solvent occurs during agitation;
4) Vapors from the solvent bath are emitted in exhaust air; and
5) Solvent losses occur during waste solvent handling.

The fraction of emissions from each of these places depends on the type of degreaser. Table 11-1 summarizes emissions from each source for the three types of cleaners.

TABLE 11-1. PERCENTAGE OF TOTAL HC EMISSIONS FROM FIVE SOURCES IN DEGREASING OPERATIONS[1]

Source of Emission	Cold Cleaner	Open-Top Vapor Cleaner	Conveyor Vapor Cleaner
Diffusion-Evap.	20%	40%	10%
Carryout	5%	10%	65%
Agitation	10%	Nil	Nil
Exhaust	5%	30%	10%
Waste Solvent Handling	60%	20%	15%

Solvent emissions resulting from diffusion and evaporation are caused by failure to close the cover when parts are not being handled. There is a vapor/air interface at the top of the vapor zone. The evaporated solvent mixes with the air due to drafts and the action of parts being inserted and removed. Warm solvent-laden air is carried upward by convection, and the solvent vapors diffuse into the room. For cold cleaners and open top vapor degreasers, these emissions depend on the care taken by operators to keep the covers closed, to handle parts efficiently and to control the heating-cooling rates. The automated conveyorized degreasers often have hoods to collect vapors and operators do not open and close the doors.

Carry-out emissions result from entrainment of liquid and solvent vapors as clean parts are removed from the degreaser. This problem can be complicated by the shape of the part. Crevices and cupped portions may retain solvent even after the part appears to be dry. Drainage facilities are used to control emissions from cold cleaners. There are no special controls for open top vapor degreasers. Drying tunnels and rotating baskets are used for conveyorized cleaners. Carry-out emissions are usually the major emission source for conveyorized degreasers because of the inherently large work load. Carry-out emissions can be appreciable if proper materials handling procedures are not followed. Proper drainage of the parts is completely under the operator's control for both cold and open top vapor degreasers and is partly under their control for conveyorized degreasers. Crevices must be drained (ASTM recommends 15 seconds) and the liquid should be returned to the degreaser. These emissions are collectable only when a "drying tunnel" is provided as is sometimes done with conveyorized degreasers.

Agitation is a source of emissions only for cold cleaners. Emission rates from agitation depend on the use of a cover, the type of agitation, and adjustments to the agitation system. Emissions are normally insignificant if the cover is closed during agitation. By careful operation at a low spray pressure and sensible design the emissions from spray evaporation can almost be eliminated. None of these emissions are collectable unless the entire unit is hooded.

Exhaust emissions result when exhaust rates for open top vapor degreasers and conveyorized degreasers are set too high. An excessive exhaust rate disrupts the vapor/air interface and causes more solvent vapors to mix with the air which is carried out by the exhaust system. The exhaust rates can be controlled by the operator on both types of degreasers. When an induced draft fan is employed for the exhaust, these vapors are almost entirely collectable.

Waste solvent evaporation is a source of emissions for all three types of degreasers, although to varying degrees. The amount of waste solvent evaporation is a function of the quantity of waste solvent handled and the method of disposal. Unacceptable disposal routes include flushing down sewers, spreading on dirt roads for dust control, and landfilling where evaporation or soil leaching can occur.

11.2 Levels and Sources of Emissions

The Nashville area has an estimated 290 tons/year of solvent emissions from degreasing. These emissions account for about 2 percent of the total stationary source hydrocarbon emissions. These emissions are from major and minor sources in three counties, with none from Davidson County. Area source degreasing emissions probably exist in Davidson County but the magnitude is unknown.

Table 11-2 shows the degreasing emissions in the Nashville area by counties and describes the types of sources contributing the emissions. Conveyorized cleaners produce 66 percent of the solvent emissions and open top vapor degreasers produce about 33 percent.

11.3 Control Technology

Control methods for degreasing emissions include the improvement of operating procedures and housekeeping practices, upgrading of equipment or instrumentation, and add-on devices such as condensers and adsorbers.

Solvent reclamation is considered the best method for reducing emissions from evaporation of waste solvent since almost 90 percent of the solvent is recovered as usable product. Reclamation can be done through a private contractor or in-house distillation. Good operating practice is needed to keep water separators performing well, to collect all waste and to prevent spills. These emissions are collectable if a well designed solvent reclamation system is used.

Imp[illegible] housekeeping and operating procedures can be used to achieve a [illegible] to 30 percent reduction in total emissions[2] by preventing some of the diffusion-evaporation and carryout emissions and most of the waste solvent emissions.

Such control methods for cold cleaners include the following improvements to equipment and operating practices.[2]

1) Install a cover.
2) Install a facility for draining cleaned parts.
3) Post a permanent, conspicuous label summarizing the operating requirements.

TABLE 11-2. SUMMARY OF DEGREASING EMISSIONS IN THE STUDY AREA

Emission Source	Type of Degreasing Operation	Hydrocarbon Emissions (tons/yr)
Rutherford County		
SD-2 (Motor Assembly)	Conveyor	13.3
SD-1 (Unknown)	Open Top	15.0
DG-1 (Unknown)	Cold	0.6
DG-2 (Electric Motors)	Conveyor	109.6
	Other	2.0
Williamson County		
DG-3 (Heat Exchangers)	Open Top	17.9
DG-4 (Unknown)	Open Top	2.3
DG-5 (Unknown)	Open Top	19.4
Wilson County		
SD-3 (Manufacturer)	Open Top	40.4
DG-6 (Unknown)	Conveyor	70.3

4) Employ a waste solvent disposal method that prevents evaporation of more than 20 percent of the solvent. Store waste solvent only in covered containers.
5) Close cover when parts are not being treated in the cleaner.
6) Drain cleaned parts for 15 seconds or until dripping ceases.

Controls for open top vapor degreasers include the following improvements to equipment and operating practices.

1) Install a cover that can be opened and closed easily without disturbing the vapor zone.
2) Keep cover closed at all times except when processing work loads through the degreaser.
3) Minimize solvent carry-out by the following four measures:
    a) Rack parts to allow full drainage.
    b) Move parts in and out of the degreaser at less than 3.3 m/sec (11 ft/min).
    c) Cook the work load in the vapor zone at least 30 sec or until condensate ceases.
    d) Tip out any pools of solvent on the cleaned parts.
    e) Allow parts to dry for 15 seconds or until fully dry.
4) Do not degrease porous, absorbent materials, such as cloth, leather or rope.
5) Work loads should not occupy > 50 percent of the open top area.
6) The vapor level should not drop > 10 cm (4 in) during operation.

7) Never spray above the vapor level.
8) Repair solvent leaks immediately, or shut down the degreaser.
9) Employ a waste solvent disposal method that prevents evaporative losses of more than 20 percent of the solvent. Store waste solvent only in covered containers.
10) Exhaust ventilation should not exceed 20 m^3/min per m^2 (65 cfm per ft^2) of degreaser open area, unless necessary to safely achieve the TLV requirements set by OSHA. Ventilation fans should not be used near the degreaser opening, so that drafts are created in the degreaser.
11) Water should not be visually detectable in solvent exiting the water separator.

Controls for conveyorized degreasers include the following operating practices.

1) Exhaust ventilation should not exceed 20 m^3/min per m^2 (65 cfm per ft^2) of degreaser opening, unless necessary to safely achieve TLV requirements set by OSHA. Do not direct fans toward the openings.
2) Carry-out emissions should be minimized by:
    a) Racking parts for best drainage.
    b) Maintain conveyor speed at $<$ 3.3 m/min (11 ft/min).
3) Employ a waste solvent disposal method that prevents evaporative losses of more than 20 percent of the solvent. Store waste solvent only in covered containers.
4) Repair solvent leaks immediately, or shut down the degreaser.

5) Water should not be visibly detectable in the solvent exiting the water separator.

Add-on control devices applicable to degreasing operations include carbon bed adsorbers and condensers. Application of these add-on devices requires that the waste stream be "collected". Table 11-3 describes which emissions are collectable and specifies selected control methods for each emission source.

Carbon bed adsorption was selected instead of condensers because of its potentially higher efficiency for control of the collectable emissions and because refrigeration utility is not usually available. About half of the total emissions are collectable and a 90 percent recovery of these in a carbon bed is assumed possible.

TABLE 11-3. COLLECTABLE EMISSIONS AND CONTROL METHODS FOR HYDROCARBONS FROM DEGREASING OPERATIONS

Source of Emissions	% Collectable*	Control Method
Diffusion-Evaporation	0 - 50	Carbon Adsorption
Carryout	0 - 95	Carbon Adsorption
Agitation	0	Operator Care
Exhaust	0 - 95	Carbon Adsorption
Waste Solvent	0	Reclamation

*Depends on type of degreaser, low values in cold cleaners and high values in either open top vapor or conveyorized.

Degreasing solvent emissions in the study area could be reduced to about 200 tons/year with improved housekeeping and operating practices (30% overall control efficiency). Application of carbon adsorption (50% overall control efficiency) to the remaining emissions would further reduce emissions to about 100 tons/year.

11.4 Capital and Operating Costs

Capital and operating costs for improved housekeeping and operating practices and equipment upgrading are negligible and they are readily paid for by credit for solvent recovered. Capital costs for instruments and sliding covers and operating costs for operator training and, possibly, some increase in supervision are minor. The credit for recovery of solvent by these expenditures will be greater than the costs.

Costs for retrofit carbon adsorption controls on model open top vapor degreasers and monorail and cross-rod conveyorized degreasers have been estimated.[2] Table 11-4 summarizes the characteristics of the model plants. The working area and the solvent emissions rate are the two parameters used to characterize the size of the degreasers. Capital costs, net annualized costs, and cost effectiveness of carbon adsorption for the model plants are shown in Table 11-5.

11.5 Economic Impact of Control Costs

Little information is available about the economic impact of control measures for the degreasing industry. Costs for improved housekeeping and operating procedures will have negligible economic impact. Carbon adsorption units cost as much as twice the cost of the actual degreasing equipment.[3] However, the open top and conveyor degreasers are only very small parts of the facilities which use them.

TABLE 11-4 MODEL PLANT PARAMETERS USED IN ESTIMATING COST OF CARBON ADSORPTION CONTROLS FOR DEGREASING OPERATIONS[2]

Plant Parameter	Open Top Vapor Degreaser	Monorail Conveyorized Degreaser	Cross-Rod Conveyorized Degreaser
Working Area (m^2)	1.67	3.9	3.9
Uncontrolled Emission Rate (tons/yr)	10.5	38.5	15.4
Emission Rate After Housekeeping Improvements (tons/yr)	7.4	28.6	11.6
Solvent Recovered by Carbon Adsorption (tons/yr)	3.6	14.4	5.8
Solvent Cost ($/lb)	0.195	0.195	0.195

TABLE 11-5. CAPITAL AND ANNUAL COSTS FOR CONTROL OF HYDROCARBON EMISSIONS FROM TYPICAL DEGREASING OPERATIONS USING CARBON ADSORPTION[2]

Type of Degreaser	Uncontrolled Hydrocarbon Emissions (tons/yr)	Solvent Recovered (tons/yr)	Installed Cost of Carbon Bed Absorber[a] ($1000)	Operating Costs ($/yr)				Cost Effectiveness ($1000/ton Controlled)
				Capital[b] Charges	Direct[c] Operating Cost	Solvent[d] Recovery Credit	Net[e] Operating Cost	
Open top vapor	10.5	3.63	10.3	1765	451	(1416)	800	0.22
Conveyorized (Monorail)	38.6	14.4	17.6	3017	970	(5616)	(1629)	(0.113)
Conveyorized (Cross-rod)	15.4	5.8	17.6	3017	754	(2258)	1513	0.26

[a] Retrofitted

[b] Capital charges at 10 percent interest, 15 year depreciation; plus 4% of capital for taxes, insurance, and administration

[c] Labor, utilities, and materials plus 2% of capital for maintenance

[d] Solvent credited at $0.195/lb recovered

[e] Capital charges + direct operating cost - solvent recovery credit

11.6 References

1. Radian Corporation, Control Techniques for Volatile Organic Emissions from Stationary Sources, draft report, DCN 200-187-12-07, EPA Contract No. 68-02-2608, Task 12, Austin, Texas, September 1977.

2. Environmental Protection Agency, Emission Standards and Engineering Division, Chemical and Petroleum Branch, Control of Volatile Organic Emissions from Solvent Metal Cleaning, EPA-450/2-77-022 (OAQPS No. 1.2-079). Research Triangle Park, North Carolina. November 1977.

3. Burr, Richard K. and Paul A. Boys. Systems and Costs to Control Hydrocarbon Emissions from Stationary Sources. Research Triangle Park, N.C., EPA. 1973.

4. Environmental Protection Agency, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards. Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. Research Triangle Park, North Carolina. May, 1977.

5. PEDCo-Environmental Specialists, Inc. Hydrocarbon Area Source Emission Inventory for Cheatham, Davidson, Robertson, Rutherford, Sumner, Williamson and Wilson Counties, Tennessee. EPA Contract No. 68-02-1375, Task Order No. 9. Cincinnati, Ohio. July, 1976.

APPENDIX A

CONVERSION FACTORS TO SI MEASUREMENTS

A complete description of conversion factors to the International System of Units (SI) is found in the "Metric Practice Guide," American Society for Testing and Materials, pub. #E 380-72, approved by the American National Standards Institute, Std. #Z210.1-1973. The following are selected conversion factors that will accommodate all units found in this report as well as other pertinent units. They are arranged alphabetically.

To Convert From	To	Multiply By
atmosphere (normal=760 torr)	pascal (Pa)	$1.01325 * 10^5$
British thermal unit [+](Btu)	joule (J)	$1.05506 * 10^3$
Btu/ft^2	joule/metre^2 (J/m^2)	$1.13565 * 10^4$
Btu/hour	watt (W)	0.29307
Btu/pound-mass	joule/kilogram-(J/kg)	$2.326 * 10^3$
Btu/lbm•deg F (heat capacity)	joule/kilogram-kelvin (J/kg•K)	$4.18680 * 10^3$
Btu/s•ft^2•deg F	watt/metre^2-kelvin (W/m^2•K)	$2.04418 * 10^4$
calorie (International Table)	joule (J)	4.18680
day	second (s)	$8.64000 * 10^4$
degree Celsius (C)	kelvin (k)	$t_k=t_c + 273.15$
degree Fahrenheit (F)	degree Celsius	$t_c=(t_f-32)/1.8$
degree Fahrenheit (F)	kelvin (k)	$t_k=(t_f+459.67)/1.8$
foot (ft)	metre (m)	0.30480
foot^2 (ft^2)	metre^2 (m^2)	$9.29030 * 10^{-2}$
foot^3 (ft^3)	metre^3 (m^3)	$2.83168 * 10^{-2}$
foot/hour (fph)	metre/second (m/s)	$8.46667 * 10^{-5}$

[+] The Btu quantity used herein is that based on the International Table.

To Convert From	To	Multiply By
foot/minute (fpm)	metre/second (m/s)	$5.08000 * 10^{-3}$
foot/second (fps)	metre/second (m/s)	0.30480
foot^3/minute (cfm)	metre^3/second (m^3/s)	$4.71947 * 10^{-4}$
foot^3/second (cfs)	metre^3/second (m^3/s)	$2.83168 * 10^{-2}$
gallon (U.S. liquid)(gal)	metre^3 (m^3)	$3.78541 * 10^{-3}$
gallon (U.S. liquid)/day (gpd)	metre^3/second (m^3/s)	$4.38126 * 10^{-8}$
gallon (U.S. liquid)/minute (gpm)	metre^3/second (m^3/s)	$6.30902 * 10^{-5}$
grain (gr)	kilogram (kg)	$6.47989 * 10^{-5}$
horsepower (hp)	watt (w)	$7.46000 * 10^{2}$
hour (hr)	second (s)	$3.60000 * 10^{3}$
inch (in)	metre (m)	$2.54000 * 10^{-2}$
inch^2 (in^2)	metre^2 (m^2)	$6.45160 * 10^{-4}$
inch of water (60 F)	pascal (Pa)	$2.4884 * 10^{2}$
kilowatt-hour (kwh)	joule (J)	$3.60000 * 10^{6}$
minute (min)	second (s)	60.000
parts per million (ppm)	milligram/metre^3 (mg/m^3)	(molecular weight)/ 24.5
pound-force (lbf avoirdupois)	newton (N)	4.44822
pound-force/inch^2 (psi)	pascal (Pa)	$6.89476 * 10^{3}$
pound-mass (lbm avoirdupois)	kilogram (kg)	0.453592
pound-mass/foot^3 (lbm/ft^3)	kilogram/metre^3 (kg/m^3)	$1.60185 * 10^{1}$
pound-mass/minute (lbm/min)	kilogram/second (kg/s)	$7.55987 * 10^{-3}$
pound-mass/second (lbm/sec)	kilogram/second (kg/s)	$4.53592 * 10^{-1}$
ton (cooling capacity)	Btu/hr	$1.2000 * 10^{4}$
ton (short, 2000 lbm)	kilogram (kg)	$9.07185 * 10^{2}$